TP 13593E

Design of an Optical Ranging System for Full-Scale Measurement of Icebreaker Propeller Blade Deflection

Prepared for
Transportation Development Centre
Transport Canada

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by

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Metricomp Systems

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16. Abstract

Navigating in arctic waters presents a formidable challenge to a ship's propulsion systems as large ice pieces impinging on its propeller blades may result in stresses exceeding the strength of the blade material. Damage to propellers is costly and can also lead to disaster if a ship becomes disabled in a remote area. To prevent such situations, design practice must be improved and validated against experimental data.

This report presents the design of a system that performs ice load measurements. This system is based on conventional triangulation and uses three laser range finders aimed at the propeller blades to monitor deformations in real time. As the propeller rotates, each laser range finder describes an arc of a circle on the blades. Using template-matching techniques, the range values for these series of arcs can be used to infer the actual ice-induced blade deformations. The system provides range measurements at a rate of 1 kHz on three different channels. The system accuracy is 0.5 mm at distances in excess of 3 m.

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16. Résumé

La navigation dans les eaux arctiques constitue un formidable défi pour les systèmes de propulsion de navires lorsque leurs hélices sont percutées par d'énormes morceaux de glace, entraînant ainsi des contraintes qui peuvent parfois excéder la limite d'endurance des pales. Les dommages à une hélice sont très coûteux et peuvent même entraîner un désastre si un navire devient inopérable dans une région reculée. Afin de prévenir de telles situations, les pratiques de conception doivent être améliorées et validées à l'aide de mesures expérimentales.

Ce rapport présente la conception d'un système permettant de mesurer les charges de glace appliquées aux pales d'une hélice. Le système est basé sur le principe de la triangulation conventionnelle et utilise trois télémètres laser pointés sur les pales de l'hélice afin de mesurer leurs déformations en temps réel. Lorsque l'hélice tourne, chaque télémètre laser décrit un arc de cercle sur les pales. En utilisant des techniques de reconnaissance de formes, le déplacement le long de ces séries d'arcs peut être utilisé afin de déduire la déformation induite par la glace. Le système peut mesurer les déflexions au rythme de 1 000 échantillons par seconde pour chacun des trois canaux. La précision du système est de 0,5 mm à une distance pouvant aller jusqu'à 3 m.

17. Mots clés

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Executive Summary

Transport Canada, Prairie and Northern Region Marine Safety, as the regulatory body responsible for marine safety and marine pollution control regulations, is an active participant in, and proponent of an international effort to develop a harmonized Code of Polar Navigation intended to provide a uniform, internationally recognized regulatory regime for the construction and operation of ships for service in the severe ice conditions of the polar regions. In the past several years, substantial progress has been made in the development of this new regime with active participation by most of the nations operating polar-capable ships and by most of the world's major ship classification societies.

For many years now, it has been well understood that the passages and coastlines of the Canadian Arctic Archipelago tend to trap extensive pans of thick sea ice, causing them to remain at high latitudes for many years on end, progressively losing brine volume and acquiring greater mechanical strength as they survive multiple seasonal freeze-thaw cycles. These passageways are also commonly infested with icebergs and smaller fragments of very strong ice shed from the glaciers along the coastlines of the larger islands of the archipelago, as well as from the Greenland coast. As a result, the navigable waterways of the Canadian Arctic arguably contain the most severe ice conditions, from the point of view of marine navigation, that can be found anywhere in the northern hemisphere.

It is important to Canada to ensure that the unique and severe ice conditions of the Arctic, and the requirements that they impose for safe and effective marine navigation, are fully appreciated and considered by the international body of experts developing the internationally harmonized Code of Polar Navigation.

A major contribution of Transport Canada to this effort has been the systematic conduct of full-scale measurements of sea ice loads acting on the hulls, propellers and rudders of icebreaking shipping in the severe ice conditions that can be found in the Canadian Arctic. As propellers are one of the most vulnerable components of ice-going ships, and experience significant ongoing rates of failure when operating in thick multi-year ice in particular, a number of full-scale measurement programs have been conducted during the past 20 years to help quantify and better understand the ice loading of propellers on different types of vessels and in different ice regimes.

These experiments originally focused on the use of conventional foil resistance strain gauges, of the type widely used in structural mechanics investigations, as the primary load-sensing tool. These sensors were typically embedded within the propeller blades to measure the dynamic stresses caused by impact of the blades with ice fragments passing underneath the hull. A more recent development of the technique led to the successful use of fibre-optic strain gauges embedded in a blade of a high-powered icebreaker propeller to increase the ruggedness of the installation, improve signal-to-noise characteristics and substantially increase the number of sensors that could be used to reach the spatial resolution of dynamic stress mapping within the blade.

In 1996, the Transportation Development Centre (TDC) of Transport Canada, which has acted as scientific project manager of all of the significant full-scale propeller-ice load measurement programs undertaken to date in Canada, became interested in the possibility of a non-contact technique for measuring propeller blade ice loads. This would make it practical to study a wider range of propeller designs than could be instrumented with blade-embedded strain gauges and also offered the possibility of substantially reducing the engineering, fabrication and instrumentation costs associated with carrying out measurements on multiple installations.

The same year, a feasibility study was undertaken for TDC by the same authors of this report to evaluate the options for such an approach. Several candidate techniques, based on optical range measurement, for the evaluation of the dynamic bending deflections of propeller blades under ice loads were investigated. The major result of this study identified an active triangulation ranging technique as the most promising approach for measuring dynamic blade deflections to compute the associated ice loads. In this technique, a light spot is projected onto the suction side of the propeller blades using a laser source having a wavelength optimized for underwater transmission. A linear photodiode array is used to detect this spot from another location near to, but separated by a fixed and significant distance from the laser source. Using a known geometry and the measured displacement of the spot image along the detector linear array, it was confirmed using laboratory tests that it is possible to determine the range from the detector to the blade suction side with high accuracy and enough speed to be able to resolve the dynamic vibrations of the blade due to impact with large ice fragments.

The current project was then launched to design and construct a prototype instrument suitable for conducting full-scale measurements on an icebreaker. An Optical Load Deflection System (OLDS) was designed and constructed by the Institut national d'optique (INO). The OLDS is composed of a laboratory environment power and control unit, containing three independent laser sources and data acquisition electronics, connected by a sturdy umbilical cable to an underwater enclosure that would be mounted to the propeller bossing in a specially constructed ice-strengthened fixture. The underwater enclosure contained the emission optics to project three widely spaced laser beams onto the suction side of the propeller blades as they pass through the top dead centre position of the disk, and the collection optics to image each of the three laser spot images on the blade. The emission and collection optics assemblies were all mounted behind thick Lexan windows set in a heavy stainless steel face plate on the rear facing side of the enclosure to ensure that the instrument, once installed on the bossing, would be able to withstand mechanical impact with large pieces of ice.

Concurrently with the development of the OLDS package, the project team began to evaluate candidate icebreaking vessels and deployment opportunities to carry out the first set of full-scale measurements using this new technology. Early in 1999, it was identified that the most suitable candidate vessel for the initial use of the OLDS would be the Canadian Coast Guard's (CCG) heavy icebreaker CCGS *Louis S. St. Laurent*. The ship was to be dry-docked in the spring of 1999, affording an opportunity to fit the ice-strengthened fixture. The ship would then be deployed to the Canadian Arctic where it would close out the shipping season in late autumn, affording a good possibility of encountering heavy multi-year ice that would generate significant ice loading of the propellers. Moreover, this ship was also planned to be fitted in 2000 with new stainless steel bladed propellers, replacing the manganese-aluminium bronze monoblock propellers that it would be using in 1999. By conducting an initial set of trials on this vessel in 1999, and then again in 2000, it would be possible to obtain ice load measurements from two significantly different propeller designs on the same vessel and potentially in similar ice conditions. For the cost of a single ship installation, this represented a valuable opportunity that had never been available previously.

In early 1999, two new manganese-aluminium bronze propellers were manufactured for the wing shafts of the CCGS *Louis S. St. Laurent* to replace ones that had been damaged during late season operations in 1998. In early March 1999, the propeller manufacturer, working under the coordination of the project team, constructed a calibration load frame for the new port propeller that had been identified as the one that would be instrumented using the OLDS for the initial set of ice trials. At the Stone Marine propeller foundry at Iberville (Quebec), the port propeller was calibrated by applying known loads to each of the four blades of the new port propeller using hydraulic jacks to measure their load-deflection characteristics and obtain experimental data on their bending stiffness distributions. This data was subsequently used to verify numerical models of the blade stiffness characteristics developed to translate the measured blade deflections due to ice impacts into blade loads.

Stone Marine was also contracted at this time to lightly sandblast the suction sides of the four blades of the port propeller between the 0.6 relative radius and the tips to eliminate the fine parallel surface striations left by the finish machining, thereby improving the isotropy of the surface reflectivity. This would help to reduce the fluctuations in the brightness of the laser-illuminated spots on the blades as they rotate.

In late March and early April 1999, the newly manufactured propellers were fitted to the CCGS *Louis S. St. Laurent* in dry-dock in Halifax (Nova Scotia). During this dry-docking period the shipyard was subcontracted by CCG to construct and fit an ice-strengthened "shoe", designed by the OLDS team, to the top of the port bossing approximately 2.5 m forward of the propeller. This work also involved welding and fairing an ice-strengthened cable conduit to the outside of the hull, extending from the ice-strengthened shoe up the side of the hull to the main deck level. Power and fibre-optic conductors were connected through a 1 in. diameter umbilical cable passing from the data collection centre in one of the ship's labs, down through the faired conduit on the hull and to the OLDS underwater package.

Because of concern for marine fouling of the optical windows between the time of the dry-docking in the spring and the time of the trials in the autumn, the OLDS underwater instrument package was not fitted in the ice-strengthened shoe while the ship was in dry-dock. Instead the underwater instrument package and the associated umbilical cable were designed so that they could be installed by divers in the Arctic just prior to the conduct of the trials.

Sommaire

Transports Canada, Sécurité maritime région des Prairies et du Nord, est l'organisme chargé de réglementer la sécurité maritime et la prévention de la pollution marine. À ce titre, l'organisme fait une promotion soutenue de l'adoption d'un Code de navigation polaire harmonisé et participe activement aux travaux à cet égard. Ce Code établira un régime réglementaire uniforme reconnu à l'échelle internationale pour la construction et l'exploitation de navires adaptés à la navigation dans les conditions de glace très difficiles des régions polaires. Ces dernières années, l'élaboration d'un tel régime a fait des progrès appréciables grâce à la participation de la plupart des pays qui exploitent des navires en eaux polaires et de la plupart des sociétés de classification des navires.

Depuis de nombreuses années, on sait que les passages et les côtes de l'archipel Arctique canadien retiennent de grandes plaques de glace épaisses, qui restent ainsi à des latitudes élevées pendant plusieurs années. Peu à peu, le volume d'eau salée diminue et la résistance mécanique des glaces augmente au gré des cycles saisonniers de gel et de dégel. Ces passages sont aussi souvent parsemés d'icebergs et de plus petits fragments de glace très solide qui proviennent des glaciers des côtes des grandes îles de l'archipel et du Groenland. En raison de tous ces obstacles, il n'est pas exagéré d'affirmer que les conditions de glace des voies navigables de l'Arctique canadien sont parmi les plus difficiles à emprunter de tout l'hémisphère nord.

Le Canada doit par conséquent s'assurer que les caractéristiques uniques et dangereuses des régimes de glaces de l'Arctique, de même que les exigences qu'elles imposent au chapitre de la sécurité et de l'efficacité de la navigation maritime, sont bien comprises par les experts du monde entier et qu'ils en tiennent compte dans l'élaboration d'un Code harmonisé de navigation polaire.

L'un des apports de Transports Canada à cette initiative a été de mesurer de façon systématique, en milieu réel, les charges de glace appliquées sur la coque, les hélices et les gouvernails de brise-glaces qui naviguent dans les difficiles conditions de l'Arctique canadien. Les hélices sont certainement les composantes les plus fragiles de ces navires qui sillonnent de telles régions et leur taux de défaillance (bris) est particulièrement élevé dans les glaces épaisses formées depuis plusieurs années. C'est pourquoi divers programmes de mesure en milieu réel ont été menés au cours des 20 dernières années afin de quantifier et améliorer notre compréhension de la force exercée par les glaces sur les hélices de différents types de navires et dans différents régimes de glaces.

À l'origine, la mesure des charges était effectuée à l'aide de jauges de contraintes conventionnelles de type résistif, largement utilisées pour les recherches en mécanique structurale. Le plus souvent, ces capteurs étaient enchâssés dans les pales des hélices afin de mesurer les contraintes dynamiques découlant des chocs entre les pales et les fragments de glace qui passent sous la coque. La technique a progressé depuis et des jauges de contraintes à fibre optique ont récemment été enchâssées dans une pale de l'hélice d'un brise-glace afin d'augmenter la robustesse de l'installation, d'améliorer les caractéristiques du rapport signal sur bruit et d'augmenter de façon sensible le nombre de

capteurs utilisés de manière à augmenter la résolution spatiale des images de contraintes dynamiques appliquées à la pale.

En 1996, le Centre de développement des transports (CDT) de Transports Canada, qui a fait office de gestionnaire de projet scientifique pour tous les principaux programmes de mesure en milieu réel des charges de glace sur les hélices qui ont été réalisés à ce jour au Canada, s'est intéressé à une technique de mesure sans contact. Cette nouvelle technique permettrait de mener des études sur des modèles variés d'hélices, ce que ne permettent pas les jauges de contraintes à fibres optiques intégrées aux pales et réduirait par ailleurs sensiblement les coûts d'ingénierie, de fabrication et d'instrumentation inhérents aux mesures faites sur de multiples installations.

La même année, les auteurs de ce rapport ont effectué pour le CDT une étude de faisabilité qui visait à évaluer les options liées à cette nouvelle approche. Diverses techniques faisant appel à des dispositifs optiques de mesure de distance ont été étudiées afin de mesurer la déflexion dynamique des pales des hélices sous la poussée des glaces. Cette étude identifiait la télémétrie par triangulation active comme étant l'approche la plus prometteuse permettant de mesurer les déflexions dynamiques des pales et de calculer les charges de glace associées à ces déflexions. Selon cette technique, un point lumineux est projeté sur la face avant des pales de l'hélice à l'aide d'une source laser dont la longueur d'onde est optimisée pour la transmission sous-marine. Une matrice linéaire (barrette) de photodiodes est utilisée afin de détecter l'image de ce point lumineux à partir d'un autre emplacement à proximité mais séparé par une distance fixe et appréciable de la source laser. À partir d'une géométrie connue et de la mesure du déplacement de l'image du point lumineux le long de la matrice linéaire de photodiodes, il a été confirmé en laboratoire qu'il est possible de déterminer avec une grande précision la distance entre le capteur et la face avant de la pale, ceci assez rapidement pour résoudre les vibrations dynamiques appliquées à la pale par de gros fragments de glace.

Suite à cette étude, le projet actuel a vu le jour. Ce projet visait à concevoir et fabriquer un prototype d'instrument pouvant effectuer des mesures en milieu réel sur un brise-glace. L'Institut national d'optique (INO) a donc conçu et mis au point un système optique de mesure de la déflexion des pales d'hélice (appelé OLDS). Le OLDS est composé d'un bloc de commande et d'alimentation installé dans un laboratoire du navire - doté de trois sources laser indépendantes et d'un dispositif électronique de collecte des données - raccordé par un lien ombilical robuste à un boîtier submersible fixé à la coque du navire dans un support spécialement renforcé pour résister aux chocs de fragments de glace. Le boîtier submersible contient l'optique d'émission qui projette trois faisceaux laser très espacés sur la face avant des pales de l'hélice au moment où elles passent par le point supérieur du disque, ainsi que l'optique de collection qui image chacun des trois points laser projetés sur la pale. Les dispositifs optiques d'émission et de collection sont installés derrière des vitres Lexan épaisses, insérées dans une plaque en acier inoxydable du côté arrière du boîtier, de sorte que le système submersible, une fois fixé à la coque, puisse supporter les chocs mécaniques exercés par les gros morceaux de glace.

Parallèlement à la mise au point du OLDS, l'équipe de projet a amorcé l'évaluation de quelques brise-glaces et des diverses possibilités de déploiement en vue des premiers essais en milieu réel. Au début de 1999, il a été décidé que le plus gros brise-glace de la

Garde côtière canadienne (GCC), le *Louis S. St-Laurent*, convenait le mieux pour la première utilisation du OLDS. Le support renforcé pouvait être installé à la coque au printemps 1999 lors d'une cale sèche prévue à l'horaire, diminuant ainsi considérablement les coûts du projet. Le navire devait ensuite partir pour l'Arctique canadien où il devait clore la saison de navigation à la fin de l'automne 1999. Ce retour tardif le rendait donc susceptible de rencontrer d'importantes plaques de glace de plusieurs années, favorisant ainsi l'interaction de fortes charges sur les hélices. En outre, ce navire devait être équipé de nouvelles hélices en acier inoxydable en 2000 afin de remplacer les hélices monoblocs en alliage manganèse-aluminium-cuivre utilisées en 1999. En effectuant des essais initiaux en 1999, suivis d'autres essais en 2000, la possibilité fut donc offerte d'obtenir des mesures de charges de glace sur deux modèles d'hélices très différents, pour un même navire, dans des conditions de glace potentiellement semblables, et cela avec une seule opération d'instrumentation. Il s'agissait d'une occasion fantastique et certainement unique.

Au début de 1999, deux nouvelles hélices en alliage manganèse-aluminium-cuivre ont été fabriquées pour les hélices extérieures (bâbord et tribord) du *Louis S. St-Laurent* afin de remplacer celles qui avaient été endommagées à la fin de la saison 1998. Au début de mars 1999, le fabricant de l'hélice, travaillant sous la coordination de l'équipe de projet, a construit un dispositif permettant d'appliquer des charges étalon à la nouvelle hélice bâbord choisie pour recevoir le OLDS lors des premiers essais en milieu réel. La fonderie Stone Marine, située à Iberville (Québec), a calibré l'hélice de bâbord en appliquant des charges connues à chacune des quatre pales. Pour ce faire, des vérins hydrauliques ont été utilisés pour mesurer les caractéristiques de charge et de déflexion, de sorte que les chercheurs puissent disposer de données expérimentales sur la distribution des résistances à la flexion. Ces données ont par la suite servi à vérifier les modèles numériques, décrivant les caractéristiques de résistance des pales, mis au point pour convertir la déflexion due aux impacts de glace en termes de charges appliquées sur les pales.

Stone Marine a aussi reçu le contrat de poncer légèrement la face avant des quatre pales de l'hélice de bâbord entre un rayon relatif de 0,6 et les extrémités. Cette opération a permis d'éliminer les minuscules stries parallèles laissées à la surface par l'usinage et d'améliorer par conséquent l'isotropie des réflexions optiques à la surface. Cela devait permettre de réduire les variations de luminosité des points laser sur les pales lorsque celles-ci sont en mouvement.

À la fin de mars et au début d'avril 1999, les nouvelles hélices ont été installées sur le *Louis S. St-Laurent* en cale sèche, au port de Halifax (Nouvelle-Écosse). Durant la période de cale sèche, la Garde côtière canadienne a confié au chantier naval la construction et la pose du support renforcé - conçue par l'équipe du projet OLDS - sur la coque à environ 2,5 m de l'hélice bâbord. Des travaux de soudure et de profilage ont également été réalisés afin d'installer une solide conduite de câble le long de la coque extérieure, entre le support renforcé et le niveau du pont principal. L'alimentation de même que les conducteurs à fibre optique utilisés ont été raccordés au moyen d'un lien ombilical de 1 pouce de diamètre partant du centre de collecte de données, situé dans l'un des laboratoires du navire, passant par la conduite installée le long de la coque, jusqu'au boîtier submersible.

Pour éviter l'encrassement des fenêtres optiques dû aux algues et autres particules, entre la période de cale sèche au printemps et les premiers essais prévus à l'automne, le boîtier submersible du OLDS n'a pas été installé tout de suite dans le support renforcé. En effet, le boîtier submersible et la liaison ombilicale ont été conçus de façon à ce que des plongeurs puissent les installer dans l'Arctique, juste avant les essais.

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Glossary

A/D	Analog-to-Digital
BSDF	Bi-directional Scattering Distribution Function
CCD	Charge Coupled Device
CCG	Canadian Coast Guard
CCGS	Canadian Coast Guard Service
CP	Controllable Pitch
CPP	Controllable Pitch Propeller
DSP	Digital Signal Processing/Processor
DOF	Depth Of Field
EOS	End Of Scan
FIR	Finite Impulse Response
FM	Frequency Modulated
FO	Fibre-Optic
FOV	Field Of View
GPS	Global Positioning System
IMD	Institute for Marine Dynamics
INO	Institut National d'Optique
IP	Industry Pack
LAN	Local Area Network
LVDT	Linear Variable Differential Transformer
LSSL	*Louis S. St. Laurent*
MDAS	Machinery Data Acquisition System
NA	Numerical Aperture
OLDS	Optical Load Deflection System
PDA	Photodiode Array
PIV	Peripheral Independent Variable
RPM	Revolution Per Minute
SNR	Signal-to-Noise Ratio
TC	Transport Canada
TDC	Transportation Development Centre
TTL	Transistor-Transistor Logic
USCG	United States Coast Guard
USCGC	United States Coast Guard Cutter
UTC	Universal Time Centre

1 Introduction

The use of full-scale data is essential for the validation of the analytical and numerical models of ice/propeller interaction processes used in support of the revision of the Arctic Machinery Regulations. Ideally, these measurements would be obtained for as wide a variety of conditions (ice and operating conditions, propulsion modes, etc.) as possible.

With this objective in mind, such a program was completed in 1995 with the successful use of an array of fibre-optic strain gauges embedded within one of the blades of the USCGC *Polar Star*. Nonetheless, the use of embedded instrumentation is costly and time-consuming as the hardware must be adapted to each and every ship on which the equipment is intended to be used, requiring extensive modifications to the hub and propellers as well as prolonged dry-docking periods.

On the other hand, the idea of underwater imagery has been around for a while and has been used quite extensively over the past fifteen years in connection with ship design and performance study. In Japan, a research team used strobe lights and conventional cameras to freeze the quasi-static cavitation pattern of heavily loaded tankers' blades. British researchers used laser Doppler velocimetry to evaluate the wake field of propeller outflow. More recently, underwater stereoscopy systems have been installed on board remotely operated vehicles to provide more realistic feedback to telemanipulator operators. Finally, the project team recently used underwater video imagery as an additional source of input to the data analysis of blade stress measurements.

It is in this context that, in 1996, a feasibility study conducted on behalf of the Transportation Development Centre (TDC) investigated the possibility of remotely measuring the ice-induced blade loads with optical technologies. Such a sensor could be easily adapted to a number of ships with minimum recurrent engineering and installation costs, thereby making it practical to conduct field trials on more ships than would have been possible with embedded instrumentation techniques.

The feasibility study concluded that the optical monitoring of load-induced blade deformation and deflection was within the reach of current technology. After reviewing the technologies available, the study concluded that active triangulation methods represent the most promising alternative. A preliminary design based on this approach resulted in the definition of a reference system against which the feasibility of remote optical blade load monitoring was ascertained.

This project was put forward in an attempt to develop a low-cost alternative to the fibre-optic strain gauge technology developed and used during the 1991-1996 *Polar Star* Ice Load Monitoring Program.

Another objective of the project was to develop a reusable system that could be put to use on a number of ships without significant modifications or recurrent engineering costs.

2 Objectives

Phase I of this project consisted of a feasibility study conducted in 1996.[1] Phase II sought to complete the system definition and covered all aspects of system design and engineering development. Phase III covers the field-related work, including mobilization, installation, ice field trials and data analysis issues. This report only describes Phase II.

As such, the project deals with the design, development, construction and testing of the core of a truly portable blade load monitoring system. The system will be designed to measure the blade deflections under ice impact loading. In turn, these deflections will be used to calculate the magnitude and location of applied ice loads.

3 Technical Approach

This project focused on an active triangulation-based blade load sensor, which uses cameras coupled with laser beam (or, more generally speaking, structured light) target illumination to achieve depth measurements. Fundamentally, the sensor can, through simple geometrical relationships, match the position of the laser spot image on the detector to the actual target distance. The design process, targeted performances and overall system implementation were based on the following observations and constraints:

- The hull of an icebreaker is a particularly harsh environment under which none but the most rugged sensors can operate satisfactorily.
- According to our estimates, the blade surface deviation of a Polar Class vessel from its normal position at rest is rather small, even for 400+ tons impacts. It has been calculated that this maximum deviation, which occurs at the blade tip where the cross section is minimal, is about 30 mm. Consequently, there is no point in scanning the whole surface as the deflection below the 0.7 blade radius is not significant. Moreover, full-scale experimentation of blade stresses monitoring as well as sensor calibration data realized by the proponents of this project indicate that it should be possible, with adequate models, to recover the information from those locations. Finally, the system depth of field (i.e. the range over which the system can perform measurements) should be sufficient to accommodate all blade pitches of controllable pitch propeller (CPP)-equipped vessels.
- In normal ice-going operations, any location on the blade is subject to fore and aft motion resulting from the combined effects of ice load induced deflections, pitch setting, tilting of propeller plane due to flexing of shaft as well as axial compression and axial movement in bearing due to ice impacts. To sort out the extraneous effects from the blade deflection itself, the analysis must make use of additional input from ship machinery.
- While maintaining a significant blade coverage is important to obtain meaningful data, an analysis of the problem reveals that no advantage is to be gained by steering the probing laser beam. Scanning the beam in two dimensions is

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[1] Morin A., Arsenault M., *Survey and Comparative Analysis of Ranging Techniques for Blade Load Measurement*, INO report submitted to Metricomp Systems, November 1996.

pointless, as the rotating blade already provides for scanning in one dimension. In turn, scanning in the radial dimension, once combined with the blade movement, results in a zigzag path of the laser beam, which therefore covers an area on the blade. Nonetheless, this scanning scheme can be advantageously replaced by a series of fixed-beam sensors having overlapping fields of view. This solution would allow a good blade surface coverage while increasing the system reliability through redundancy. Consequently, the multi-sensor fixed-beam approach is favoured over scanning as it is simpler and more rugged.

- Sensor sampling rate must be high enough both to provide significant information about the dynamics of ice/blade interaction and to freeze the blade rotation. Strain rates of up to 0.30 ε/s have been recorded in a previous project. Assuming a minimum of 10 points/risetime yields an absolute minimum sampling rate of 300 Hz, 1 kHz being considered a more appropriate value owing to the maximum blade rotation speed.
- As previous projects have shown, the importance of calibration is often underestimated. Calibration in open waters using the *a priori* knowledge of the blade profile is also considered desirable.

The system consists of an underwater optical unit that measures the blade deflections. In turn, the optical unit feeds a remote computer where the data is merged with secondary data streams (ship machinery, global positioning system (GPS) location and time stamps, etc.). In addition, the underwater assembly is also fitted with conventional video cameras to help in the data analysis process. The optical unit consists of three active triangulation sensors. Frequency-doubled Nd-YAG lasers are used as active illumination sources.

Target basic performances of the underwater optical reading head are:

Sampling rate:	1 kHz
Resolution:	1 mm
Standoff:	2 m
Depth of field:	1 m

4 Selection of Candidate Vessels

The candidate vessels that were considered as potential platforms for measuring blade-ice impact loads using the optical deflection sensing technique are presented in Table 1.

Ideally, we would have selected two or more possible vessels that would have reasonably similar geometric details (as far as the distance of the imaging package from the propeller and the bossing diameter are concerned) such that the same basic measurement system could be used on all of them. This would give us maximum flexibility in selecting the vessel for the initial trials and would increase the prospects for re-using the system on additional vessel types.

The vessels are selected on the grounds of a realistic combination of ship characteristics to provide data of relevance to the widest possible range of ice-going shipping vs. desired measurement system performance. In addition, the selection takes into account non-technical issues such as the vessel's planned dry-docking schedule, the level and ease of cooperation achievable with vessel owners, etc.

Table 1: Candidate vessels and selection considerations

Vessel or Class	Number of Screws	Pitch Control	Propeller Arrangement	Existing Data	Plant	Power per Shaft (kW)	Area of Operation	Suitability Ranking
USCG *Polar Class*	3	CP	Open	Yes	Geared Gas Turbine and AC-DC	14,800 and 4,450	Polar	2
CCGS *Louis S. St. Laurent*	3	Fixed	Open	No	AC-DC	6,700	Polar and Seasonal	1
USCGC *Healy*	2	Fixed	Open	No	AC-AC	11,100	Polar	1
Kapitan Khlebnikov	2	Fixed	Open	No	AC-DC	8,900	Polar and Seasonal	1
CCGS *Henry Larsen*	2	Fixed	Open	No	AC-AC	8,200	Polar and Seasonal	2
CCGS *Pierre Radisson*	2	Fixed	Open	No	AC-DC	6,800	Polar and Seasonal	2
Fennica	2	Fixed	Ducted Pods	No	Z Drive	7,500	Seasonal	3
Kontio	2	Fixed	Open	Similar	AC-AC	7,500	Seasonal	3
Uhro	4	Fixed	Open, Two Bow Propellers	Similar	AC-DC	4,050	Seasonal	3
ODEN	2	CP	Ducted	Similar	Geared Diesel	8,160	Seasonal and Polar	3
SA-15	1	CP	Open	No	Geared Diesel	10,500	Seasonal and Polar	4

Because successful measurements of blade loads were made on a controllable pitch (CP) propeller on the USCGC *Polar Star* in Antarctica in 1994-95, making additional measurements on the CP propellers of the Polar Class or the Russian SA-15 ships was considered less interesting than obtaining data for fixed pitch installations.

The *SA-15* ice-strengthened cargo ships were also considered less interesting because they are single propeller designs of deep draught. Such ships would be expected to require extended periods of observation in heavy ice before any significant ice loads would be measured since it is well understood that single propellers on the centre-line of high draught vessels have a much reduced frequency of ice interaction compared to multi-propeller and shallower draught designs.

On the other hand, the *ODEN* has a twin-ducted CP propeller configuration similar to the M.V. *Robert LeMeur* on which successful propeller blade loads measurements were made in 1984 and as such would tend to duplicate the earlier measurements, although at higher shaft power.

The Finnish icebreakers of the older *Uhro* class and the newer *Kontio/Otso* class were considered interesting because of their fixed-pitch propeller designs. These vessels, however, are specifically designed for Baltic ice navigation and are rarely if ever deployed to the Arctic, so the prospect of obtaining data in any conditions more severe than the seasonal ice cover of the Baltic was considered poor. Measurements on these vessels would also tend to duplicate earlier measurements made on propellers of Baltic ferries and tugs by Finnish researchers, although again at higher shaft power levels.

As a result of these considerations, the vessel designs considered most promising for providing useful new data using the optical blade deflection measurement technique were the triple-screw heavy Canadian Coast Guard (CCG) icebreaker *Louis S. St. Laurent*, the new United States Coast Guard (USCG) polar icebreaker *Healy* and the Russian Arctic icebreakers of the *Kapitan Khlebnikov* class. All of these ships are designed to operate in heavy polar ice conditions and all have fixed-pitch electric propulsion systems in multi-propeller configurations.

Of these three vessels, the *Louis S. St. Laurent* and the *Healy* were considered the most promising from a logistical and practical point of view for an initial trial of the Optical Load Deflection System (OLDS). Transport Canada has a long history of cooperative research projects with both the Canadian and US Coast Guards and the operational and maintenance schedules of both vessels are relatively predictable.

It was also considered valuable that both the *Louis S. St. Laurent* and the *Healy* would be dry-docked in North American ports, whereas the *Kapitan Klebnikov* class vessels would be most likely to dock in Russia or possibly Northern European or Asian ports, which would substantially increase logistics costs for carrying out instrument fitting for a Canadian-based project team.

As a result, the investigation of candidate vessels focused primarily on the *Louis S. St. Laurent* and the *Healy* as providing the best opportunities for an early implementation of the new measurement system that would also provide data of high relevance to the regulatory development process.

In the final analysis it was determined that the earliest scheduled dry-docking opportunity would take place on the *Louis S. St. Laurent* (LSSL) in the spring of 1999. In addition, two new bronze wing propellers would be delivered and fitted at this docking and there would be an opportunity to carry out physical calibration of one of these new propellers before delivery to the shipyard. This would make it much easier to perform the calibration compared with having to do it in the shipyard in coordination with the many other tasks that would be ongoing while the ship was in dry-dock. Finally, there had also been a decision by CCG to procure and fit new stainless steel propellers of a significantly different design to the *LSSL* in the future. By taking advantage of the 1999 docking opportunity, measurements could be made on one of the existing bronze propellers and the same instrument installation would then be available to make further measurements on a propeller of substantially different design at a later stage. This would effectively provide the opportunity to obtain data for two different propeller designs for the cost of a single installation.

Because of these considerations the decision was taken in February of 1999 to carry out the first implementation of the blade deflection measurement system on board the CCGS *Louis S. St. Laurent* (see Figure 1).

Figure 1: CCGS *Louis S. St. Laurent* in Arctic (October 1999)

5 Overall Experimental Design

The objectives of the experimental design are as follows:

- Determine the strength of the blades and the range of loads they can bear without damage;
- Determine the approximate magnitude of the blade deflections associated with these maximal loads;
- Determine the magnitude of blade deflections associated with other factors apart from ice loads, which have to be compensated for;
- Specify the additional measurements that should be made to permit compensation for shafting movements and to permit the parameters on which the blade ice loads depend to be measured and documented;
- Specify the locations within the propeller disk where blade deflection measurements should be made to maximize the blade ice loading information obtained and minimize the likelihood of ice pieces blocking the optical paths to the blade suction side.

5.1 Propeller Blade Strength for Stone Marine Propellers on *LSSL*

Table 2 presents a calculation of the strength of various blade sections for the Stone Marine propellers fitted on the *LSSL*. The first column of the table shows the load that would have to be applied at 0.9 R on the blade spindle axis to initiate yielding in each section of the blade. As is typical for ice-strengthened propeller blades, the most vulnerable section under tip loading is found close to 0.7 R, which will begin to yield when the applied load reaches 2.06 MN or just over 200 metric tons. This is the approximate maximum ice load that can act near the blade tip without permanent deformation of the blade occurring. In practice the load would have to be somewhat greater than this to produce plasticity over enough of the section thickness to result in visible plastic deformation.

Table 2: Strength of the Stone Marine propellers on CCGS *Louis S. St. Laurent*

Strength of Blade Sections of Stone Marine Propellers on *Louis S. St. Laurent*
Load Applied at 0.9 R on Spindle Axis to Initiate Yield

Yield Strength of Blade Material **327 Mpa**
Propeller Radius **7.5 feet (2.286 m)**

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
0.90	43.422	3.090	1.103	0.078	0.000668	
0.80	54.000	4.300	1.372	0.109	0.001608	2.2997
0.70	58.844	5.520	1.495	0.140	0.002887	2.0649
0.60	60.000	6.730	1.524	0.171	0.004376	2.0865
0.50	59.031	7.950	1.499	0.202	0.006007	2.1483
0.40	56.172	9.160	1.427	0.233	0.007589	2.1712
0.30	51.578	10.380	1.310	0.264	0.008948	2.1333

5.2 Blade Deflection Magnitudes

As described in section 13 of this report, the relationship between applied bending load and blade deflection was experimentally determined for all four blades for a base loading condition. Under blade bending loads applied at 0.9 R on the spindle axis, the deflection of the blades at 0.8 R on the spindle axis was found to be approximately 1 mm for every 10 metric tons of load. This corresponds to a maximum deflection of about 20 mm, corresponding to a 200 ton tip load at the onset of blade yield.

5.3 Calculation of Propeller and Shafting Characteristics for *LSSL*

Propeller Characteristics

$P_{shaft} := 9000 \cdot hp$	$P_{shaft} = 6.711 \cdot MW$	Maximum continuous shaft power
$T_{bollard} := 900000 N$	$T_{bollard} = 900 \cdot kN$	Bollard thrust *per shaft* at full power
$n_{max} := 170 \cdot minute^{-1}$	$n_{max} = 2.833 s^{-1}$	Upper limit on propeller speed
$\omega_{max} := 2 \cdot \pi \cdot n_{max}$	$\omega_{max} = 17.802 s^{-1}$	Propeller speed in radians/sec
$D_{prop} := 15 \cdot 12 \cdot 25.4 \cdot mm$	$D_{prop} = 4.572 m$	Diameter of existing propellers
$R_{prop} := \frac{D_{prop}}{2}$	$R_{prop} = 2.286 m$	Radius of exisitng propellers

when the applied load reaches 2.06 MN or just over 200 metric tons. This is the approximate maximum ice load that can act near the blade tip without permanent deformation of the blade occurring. In practice the load would have to be somewhat greater than this to produce plasticity over enough of the section thickness to result in visible plastic deformation.

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Yield Strength of Blade Material **327 Mpa**
Propeller Radius **7.5 feet (2.286 m)**

r/R	Section Length (in.)	Maximum Thickness (in.)	Section Length (m)	Maximum Thickness (m)	Section Modulus (m^3)	Yield Force at 0.9 R (MN)
0.90	43.422	3.090	1.103	0.078	0.000668	
0.80	54.000	4.300	1.372	0.109	0.001608	2.2997
0.70	58.844	5.520	1.495	0.140	0.002887	2.0649
0.60	60.000	6.730	1.524	0.171	0.004376	2.0865
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0.40	56.172	9.160	1.427	0.233	0.007589	2.1712
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$n_{max} := 170 \cdot minute^{-1}$	$n_{max} = 2.833 s^{-1}$	Upper limit on propeller speed
$\omega_{max} := 2 \cdot \pi \cdot n_{max}$	$\omega_{max} = 17.802 s^{-1}$	Propeller speed in radians/sec
$D_{prop} := 15 \cdot 12 \cdot 25.4 \cdot mm$	$D_{prop} = 4.572 m$	Diameter of existing propellers
$R_{prop} := \frac{D_{prop}}{2}$	$R_{prop} = 2.286 m$	Radius of exisitng propellers

Blade Pitch at Selected Sections

$\phi_{0.7} := 18\cdot deg + 47\cdot arc\_minute + 3\cdot arc\_second$	$\phi_{0.7} = 18.784\,deg$
$\phi_{0.8} := 16\cdot deg + 34\cdot arc\_minute + 24\cdot arc\_second$	$\phi_{0.8} = 16.573\,deg$
$\phi_{0.9} := 14\cdot deg + 46\cdot arc\_minute + 4\cdot arc\_second$	$\phi_{0.9} = 14.768\,deg$
$\phi_{1.0} := 13\cdot deg + 23\cdot arc\_minute + 35\cdot arc\_second$	$\phi_{1.0} = 13.393\,deg$

Required Depth of Field

Section pitch is greatest at the hub and decreases toward the blade tip. As 0.7 R can be considered the lowest radius that will exhibit significant bending displacement due to out-of-plane ice loads, the required depth of field is, to a first order of approximation, given by the difference between the axial coordinates of the leading and trailing ends of this section:

$$\Delta z \approx L_{0.7}\cdot\sin(\varphi_{0.7}) = 1.495\ \text{m}\cdot\sin(18.784^\circ) = 0.481\ \text{m}$$

In fact, the required depth of field is somewhat greater than this by the amount of the maximum expected blade deflection under ice load at this section, plus the additional axial deflections due to the hull and shafting stiffness, plus the tilting of the propeller disk due to transverse bending of the shafting. Since these additions, in the worst case, would not be expected to exceed about 30 to 50 mm, a conservative design value for the required depth of field could be on about 0.6 m.

In practice, it would be important to design for a substantially greater depth of field to ensure the re-usability of the optics package on propellers of substantially different geometry.

Propeller Areal Characteristics

$AR_{disc} := 0.552$	$A_{disc} := \pi\cdot R_{prop}^{2}$	$A_{disc} = 16.417\,m^{2}$
$A_{projected} := 92.4\cdot ft^{2}$	$A_{projected} = 8.584\,m^{2}$	$\frac{A_{projected}}{A_{disc}} = 0.523$
$A_{expanded} := 98.17\cdot ft^{2}$	$A_{expanded} = 9.12\,m^{2}$	$\frac{A_{expanded}}{A_{disc}} = 0.556$

Propeller Rotational Characteristics

$R_{gyration} := 3.321\cdot ft$	$R_{gyration} = 1.012\,m$	Propeller radius of gyration
$W_{prop} := 31333\,lb$	$W_{prop} = 14.212\,tonne$	Propeller weight
$WR2 := 340423\,lb\cdot ft^{2}$	$WR2 = 1.435\cdot 10^{4}\ kg\cdot m^{2}$	Propeller angular moment of inertia

Sampling Rate

$\Delta t := 1\cdot \text{ms}$		OLDS sampling interval
$S_{rev} := \dfrac{1}{\Delta t\cdot n_{max}}$	$S_{rev} = 352.941$	Samples per revolution
$\Delta\theta := 2\,\pi\cdot n_{max}\cdot\Delta t$	$\Delta\theta = 1.02\,\text{deg}$	Degrees of rotation per sample
$\Delta C_{0.8} := 2\cdot\pi\cdot 0.8\cdot R_{prop}\cdot n_{max}\cdot\Delta t$	$\Delta C_{0.8} = 32.557\,\text{mm}$	Sample spacing at 0.8 R
$\phi_{0.8} = 16.573\,\text{deg}$	$\tan(16.573\,\text{deg}) = 0.298$	Blade section pitch at 0.8 R
$\Delta z := \Delta C_{0.8}\cdot\tan\left(\phi_{0.8}\right)$	$\Delta z = 9.689\,\text{mm}$	Sample interval range variation due to pitch at 0.8 R

Shaft Torque Strain

$D_{int\_shaft} := 21\,\text{in} + \frac{7}{8}\cdot\text{in}$	$D_{int\_shaft} = 0.556\,\text{m}$	Intermediate shaft diameter
$R_o := \dfrac{D_{int\_shaft}}{2}$	$R_o = 0.278\,\text{m}$	Intemediate shaft radius
$R_i := 0\cdot\text{m}$		Shaft is solid (no bore)
$Q_{fp} := \dfrac{P_{shaft}}{\omega_{max}}$	$Q_{fp} = 377\,\text{kN}\cdot\text{m}$	Full power torque
$\tau := \dfrac{2\cdot R_o\cdot Q_{fp}}{\pi\cdot\left(R_o^{\,4} - R_i^{\,4}\right)}$	$\tau = 11.193\,\text{MPa}$	Shear stress due to full power torque at intermediate shaft surface
$\upsilon := 0.3$	$E := 202000\,\text{MPa}$	Poisson ratio and elastic modulus for steel shaft
$G := \dfrac{E}{2\cdot(1+\upsilon)}$	$G = 7.769\cdot 10^{4}\,\text{MPa}$	Shear modulus for steel
$\gamma := \dfrac{\tau}{G}$	$\gamma = 1.441\cdot 10^{-4}$	Shear strain at full power on intermediate shaft surface
$\varepsilon_{diag} := \dfrac{\gamma}{2}$	$\varepsilon_{diag} = 72.035\,\mu\varepsilon$	Surface strain on the 45 degree helix on the intermediate shaft due to torsion at full power

Angular Displacement Between Propeller and Intermediate Shaft Due to Full Power Torque

$D_{\text{tail\_shaft}} := 25.25 \cdot \text{in}$	$D_{\text{tail\_shaft}} = 0.641\,\text{m}$	Approximate average diameter of tail shaft between propeller and intermediate shaft coupling
$R_{\text{tail\_shaft}} := \frac{D_{\text{tail\_shaft}}}{2}$	$R_{\text{tail\_shaft}} = 0.321\,\text{m}$	Approximate average radius of tail shaft
$L_{\text{tail\_shaft}} := 467.5625\,\text{in}$	$L_{\text{tail\_shaft}} = 11.876\,\text{m}$	Length of tail shaft from propeller centre plane to intermediate shaft
$J_{\text{tail\_shaft}} := \left(\frac{\pi}{2}\right) \cdot R_{\text{tail\_shaft}}^{4}$	$J_{\text{tail\_shaft}} = 0.017\,\text{m}^{4}$	Area polar moment of inertia of tail shaft
$\Theta_{fp} := \frac{\left(Q_{fp} \cdot L_{\text{tail\_shaft}}\right)}{\left(G \cdot J_{\text{tail\_shaft}}\right)}$	$\Theta_{fp} = 0.199 \cdot \text{deg}$	Angular displacement of propeller relative to intermediate shaft under full power torque
$\Delta C_{tip} := \pi \cdot D_{prop} \cdot \left(\frac{\Theta_{fp}}{2 \cdot \pi}\right)$	$\Delta C_{tip} = 7.931 \cdot \text{mm}$	Circumferential displacement of propeller tip under full power torque relative to inelastic shaft
$\Delta C_{0.8R} := 0.8 \cdot \Delta C_{tip}$	$\Delta C_{0.8R} = 6.345 \cdot \text{mm}$	Circumferential displacement of propeller at 0.8 R under full power torque relative to inelastic shaft

Thrust Strain at Intermediate Shaft Due to Bollard Thrust

$\sigma_{T} := \frac{T_{bollard}}{\pi \cdot R_{o}^{2}}$	$\sigma_{T} = 3.712 \cdot \text{MPa}$	Axial stress in intermediate shaft under bollard thrust load
$\varepsilon_{T} := \frac{\sigma_{T}}{E}$	$\varepsilon_{T} = 18.375 \cdot \mu\varepsilon$	Axial strain in interemediate shaft under bollard thrust load

Axial Displacement of Propeller Due to Elasticity of Shafting Under Bollard Thrust Load

$L_{\text{shaft\_line}} := 22.852\,\text{m}$		Length of shaft line from propeller centre plane to forward face of thrust bearing
$\Delta L := \varepsilon_{T} \cdot L_{\text{shaft\_line}}$	$\Delta L = 0.42 \cdot \text{mm}$	Axial displacement of propeller due to bollard thrust load in shaft line (upper bound estimate)

This calculated axial displacement of the propeller relative to the hull, due to the axial elasticity of the shaft line, is in fact conservatively large by roughly 20 to 30 percent.

This is because the intermediate shaft diameter used in the calculation is smaller than the length-averaged diameter for the whole shaft line by about this amount.

5.4 Required Shaft Movement Measurements for Blade Deflection Compensation

Based on the foregoing calculations, the following measurements of the propeller shaft movements were specified to be made as continuous recordings on a common time base with the OLDS blade deflection data for the propeller being interrogated by the OLDS system:

- Shaft instantaneous angular orientation with a resolution of 0.1 degrees of arc at 170 RPM and 1000 samples per second;
- Shaft axial movement with a resolution of 40 microns and a range of ±1 mm at 1000 samples per second;
- Shaft vertical and horizontal run out at the stern tube seal with a resolution of 40 microns and a range of ±2 mm at 1000 samples per second.

5.5 Required Measurements for Parametric Modeling of Ice Load Dependencies

To observe the relationship between blade ice impact loads and ship operational and environmental parameters, the following measurements and observations were specified to be made on a common time base with the OLDS blade deflection data:

- For the propeller being interrogated by the OLDS system, the propeller shaft torque and thrust;
- For the propeller being interrogated by the OLDS system, the propulsion motor current and voltage and the motor field current;
- For all three propeller shafts, the shaft speed and direction of rotation;
- The achieved angular position of the rudder;
- The speed of the ship relative to the surrounding ice cover derived from an over-the-side downward looking video camera;
- The latitude, longitude, ship speed and course over ground, gyro compass heading and universal time centre (UTC) time reference derived from the ship's GPS receiver;
- Underwater video imaging and recording of the ice interaction occurring in the portion of the propeller disk being interrogated by the OLDS system to help document ice piece sizes and interaction locations on the blades.

In addition to the foregoing, the following sea ice cover and environmental observations were specified to be made by manual and sea ice sampling observations in the various distinct ice conditions in which blade ice loads were being measured:

- Ice vertical temperature profiles based on up to 1.5 m long cores taken from the top of the ice cover using the Institute for Marine Dynamics (IMD) Rapid-Core ice coring rig;
- Ice vertical salinity profiles based on the same ice cores;
- Ice vertical density profiles based on the same ice cores;
- Ice floe thickness based on video observations of floes turning up on edge next to the hull near the shoulder of the bow as well as on imaging of the underside of the floes as they pass the stern in the field of view of the underwater video camera;
- Bridge observations of the percentage and type of sea ice cover;
- Ship operating draught fore and aft;
- Propulsion plant configuration: number of main engines online;
- Ship manoeuvring record, documenting when ramming or turning operations are undertaken in ice.

5.6 Design to Minimize Risk of Ice Occlusion of Optical Paths to the Propeller Disk

Experience of video imaging of the instrumented propeller on USCGC *Polar Star* in 1994-1995 had shown that for a camera located on the surface of the bossing several metres ahead of the propeller, the suction side of the blades would be visible to the camera for most of the time, even when ice was interacting with the blades. This is considered particularly true if the camera is placed on the upper surface of the bossing since the buoyancy of the ice pieces causes them to rise away from the surface of the bossing as they move aftward into the propeller. The video imagery showed that ice pieces would most commonly engage each propeller blade between its leading edge and tip as the leading edge rotates outboard from the top dead centre position.

Investigating the hull form and bossing arrangement of the CCGS *Louis S. St. Laurent* showed that the behaviour of the ice passing the propellers should be similar to that seen on the Polar Class since both vessels are triple-screw ships with similar stern arrangements. As in all multi-screw icebreaker configurations, the wing propellers always turn outboard at the top of the disk.

In the case of the *Louis S. St. Laurent*, however, the draught is typically held constant by ballasting such that the propellers do not see the shallow immersion that is often seen on the Polar Class when it becomes light on fuel. This would mean that there would be even less likelihood of large ice pieces encountering the lower or inboard part of the wing propeller disks than on the Polar Class. It was considered that almost all large ice pieces that would come in contact with the wing propellers during ahead operation would do so just as the blade leading edge rotated outboard of the top dead centre position between 9 o'clock and 12 o'clock of the disk looking forward in the case of the port propeller. Most of the time the blades will, in fact, impact the ice between half past 10 and 12 o'clock unless the ice piece is large enough to extend almost 4 m from the water surface to the depth of the centre of the propeller.

By locating the optics package at top dead centre on the bossing surface, deflections could be measured over a large part of the suction side of the blade with little likelihood of ice occlusion while the blade's leading edge and tip are rotating into the region where they are most likely to contact large ice pieces. At this point in the rotation any large ice pieces contacting the blade would tend to be located above and outboard of the blade face and would not block the beam even though they would be imposing large loads on the blade.

As a result of these considerations, and after examining the possible trajectories of ice blocks large enough to give rise to blade loads approaching the blade strength, it was decided to locate the optics housing at the 12 o'clock position of the propeller disk about 2.5 m forward of the propeller disk.

The axial distance from the housing to the propeller disk was selected to ensure that the optics would be far enough from the disk to provide the required depth of field to accommodate the axial range variation to the blade suction side due to the blade pitch. At this distance it was also judged that the optics enclosure would not too severely disrupt the water flow into the propeller. At the same time it is not so far away as to reduce unacceptably the optical power at the reception optics because of beam attenuation over too long a path in the sea water.

5.7 Design of Locations of Illuminated Target Spots on Propeller Disk

It was recognized early on in the OLDS instrumentation definition phase that the blade deflection should be measured simultaneously at multiple points on any given blade. This was considered important for several reasons:

- Measuring the blade deflection at multiple points would provide an element of redundancy in the instrumentation system. By designing the OLDS system to have multiple independent optical and signal paths for measuring blade deflections, failure of any one channel would still allow data to be obtained with the surviving channels.
- Multiple targeting points on the blade, if widely separated, would help to ensure that deflections would be measured on some of the channels even when others were momentarily occluded by ice pieces entering their optical paths.
- By targeting a number of points on a blade widely separated in the circumferential direction, the deflection of the blade could be tracked through a larger arc of rotation than would be possible with a single channel.
- By having some radial separation of the targeted points, observations could be made at a higher radius, where the magnitude of the bending deflection is greatest but where the risk of ice occlusion of the optical path is also greatest, as well as at a lower radius, where the likelihood of ice occlusion is less but the deflection magnitudes are also reduced.

One of the most important design choices that had to be made was the total number of optical channels to be employed in the OLDS head. In the end this choice was governed by considerations of cost and physical size of the optics package on the one hand versus the value of having more channels to measure deflections at more points on the propeller disk. The required size of the windows for the receiver optics made it impractical to consider more than three channels if the optics for all channels were to be installed in a single watertight enclosure. This was driven by the need to keep the optics package small enough that it could practically be mounted to the bossing forward of the propeller without being so large as to seriously affect the water flow into the propeller. Moreover, to mount multiple housings around the circumference of the bossing would have resulted in very significant increases in the cost of the installed instrumentation and the logistics involved in deploying and removing the optics at sea with divers.

As a result of these considerations it was decided early on to use a single optical instrumentation package containing the optics for three complete deflection measuring channels and to spread the three beams in both the radial and circumferential directions. The final arrangement of the target spots on the propeller disk is illustrated in Figure 2.

The final locations selected for the three target spots on the propeller disk were as follows:

- Beam 1: at 0.75 R and 3/8 of the blade chord inboard along this radius inboard of top dead centre.
- Beam 2: at 0.85 R and at top dead centre.
- Beam 3: at 0.80 R and 3/8 of the blade chord outboard along this radius outboard of top dead centre.

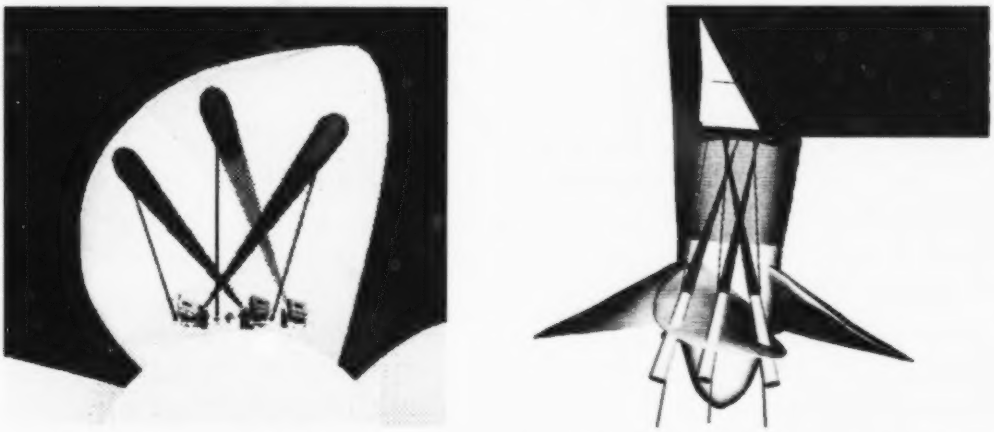

Figure 2: Location of deflection measurement points in the plane of the propeller disk

6 OLDS Architecture

OLDS architecture is based on conventional triangulation techniques and uses three laser beams aimed at the propeller blades to monitor, in real time, the deformation of their profile upon impact with ice pieces. As the propeller rotates, each point range sensor effectively describes an arc of a circle on the blades.

6.1 General Overview

The OLDS is composed of two major subsystems: an underwater housing inserted into a supporting shoe welded to the hull and a shipboard-based unit performing the control, data processing and storage functions. These two subsystems are linked together through an umbilical conduit.

The underwater subsystem comprises the emission and collection optics as well as the detection and data transmission electronics for all three channels. It also hosts a low-light charge-coupled device (CCD) camera used to record images of propeller/ice interactions. For practical purposes and improved system reliability, the lasers are located within the shipboard unit and the laser beam is delivered to the underwater subsystem through optical fibres. Figure 3 depicts an overview of the system.

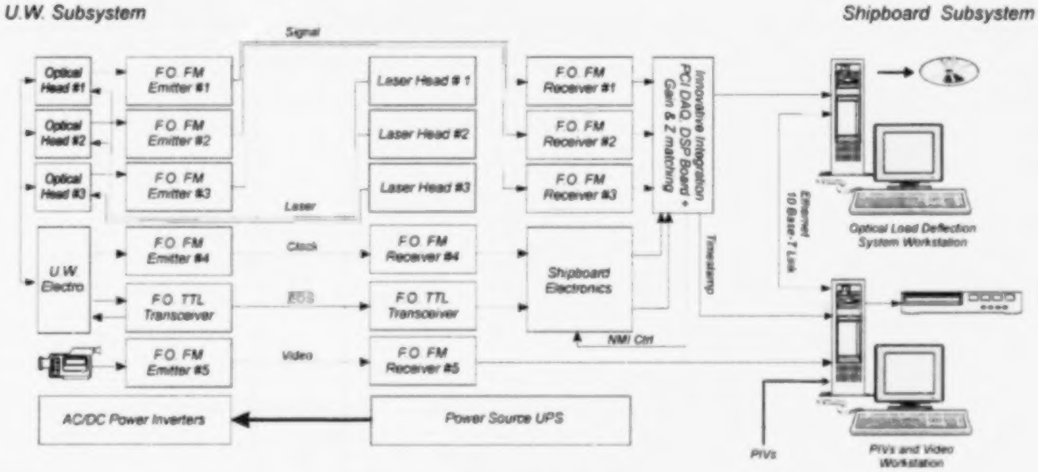
U.W. Subsystem
Shipboard Subsystem
Signal
Optical Head #1
Optical Head #2
Optical Head #3
F.O. FM Emitter #1
F.O. FM Emitter #2
F.O. FM Emitter #3
Laser Head # 1
Laser Head #2
Laser Head #3
F.O. FM Receiver #1
F.O. FM Receiver #2
F.O. FM Receiver #3
Innovative Integration PCI DAQ, DSP Board + Gain & Z matching
Laser
U.W. Electro
F.O. FM Emitter #4
Clock
F.O. FM Receiver #4
F.O. TTL Transceiver
F.O. TTL Transceiver
Shipboard Electronics
Timestamp
Ethernet 10 Base-T Link
Optical Load Deflection System Workstation
NMI Ctrl
F.O. FM Emitter #5
Video
F.O. FM Receiver #5
AC/DC Power Inverters
Power Source UPS
PIVs
PIVs and Video Workstation

Figure 3: OLDS overview

The data acquired by the underwater detection electronics is transferred to the shipboard data processing unit in an analog fashion through frequency-modulated (FM) fibre-optic links. Data is processed by digital signal processing boards piggybacked on an industrial computer running Windows NT™. A peak detection algorithm processes the data and outputs range values in real time.

In addition, ship manoeuvring parameters derived from the ship's machinery systems are recorded along with the range values to help reconstruct the ice impact events. A second computer, synchronized with the data processing computer, controls the acquisition of these parameters and handles the operation of the video camera.

6.2 Triangulation Geometry

The OLDS is based on conventional laser triangulation. The system uses linear photodiode arrays (PDAs) to monitor the scattered reflection of the laser beams aimed at the blades, the position (in pixels) of the returned signal peak intensity on the PDAs being a direct measure of the distance of the point of intersection of a given laser beam with the blade surface.

Any triangulation system can be fully described with only four basic parameters. Since the design constraints of this particular application outnumber the degrees of liberty, the design is based on a set of equations that would minimize the number of iterations required to reach an acceptable solution.

For practical purposes, three of the four basic parameters are geometric while the last is the collection optics effective focal length (f'). The three geometric parameters are the depth of field (DOF), which corresponds to the Z-axis range covered by the collection optics field of view (FOV); the standoff (S), which is the distance on the Z-axis between the collection optics principal point and the depth of field proximal point; and finally the baseline (b) measured on the X-axis as the distance between the laser projection line and a line passing by the collection optics principal point parallel to the laser projection line. The four basic parameters are described graphically in Figure 4.

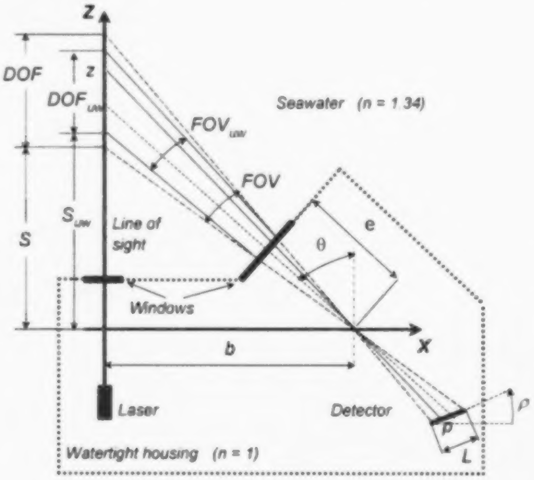

Figure 4: OLDS triangulation geometry

The aim of the design is to maintain DOF and S within the range dictated by the ship's bossing and propeller design while maximizing the resolution. Additional constraints such as the overall system size and height, and the availability of suitable detectors complete design specifications.

The design equations are as follows. The FOV as well as the triangulation angle (θ) can both be expressed in terms of the three geometric parameters:

$$FOV = \arctan\left(\frac{b}{S}\right) - \arctan\left(\frac{b}{S + DOF}\right) \tag{6.1}$$

$$\theta = \frac{1}{2}\left[\arctan\left(\frac{b}{S}\right) + \arctan\left(\frac{b}{S + DOF}\right)\right] \tag{6.2}$$

Furthermore, to maintain the focus on the detector for all range values within the depth of field, the Scheimpflug condition must be respected. This condition states that the detector must be tilted by a certain angle, called Scheimpflug angle (ρ), which is also a function of the four above-mentioned basic parameters. Thus,

$$\rho = \arctan\left(\frac{b \cdot \sin\theta - f^*}{b \cdot \cos\theta}\right) \tag{6.3}$$

The boundary condition imposes one further constraint to the design. This condition seeks to maximize both the operating range and resolution of the detector. The boundary condition states that the system should be designed so that all of the DOF but no more than that should be imaged onto the detector. This condition can be used to relate the detector physical length (L) to the four basic parameters:

$$L = \frac{b \cdot f^* \cdot DOF}{\cos\theta \cdot \sin\rho \cdot \left(b^2 \cdot \tan\rho + b(2S + DOF) + S(S + DOF)\cot\rho\right)} \tag{6.4}$$

where θ and ρ are given by equations 6.2 and 6.3.

Many numerical solutions of equation 6.4 exist. However, most of these parameters are usually constrained by design specifications. In this application though, S and DOF are restricted by the ship's bossing shape and propeller blade geometry, while L is limited by the detector's availability. Hence, b and f^* are the only remaining free variables.

For a given triangulation geometry, it is possible to express the Z-axis range distance (z) in terms of the position (p) on the detector of the maximum illuminated pixel:

$$z(p) = \frac{b \cdot N \cdot f^*(S + DOF) - p \cdot L \cdot b \cdot \cos\theta \cdot \left[(S + DOF)\sin\rho + b \cdot \tan\rho \cdot \sin\rho\right]}{b \cdot N \cdot f^* + p \cdot L \cdot \cos\theta \cdot \left[(S + DOF)\cos\rho + b\sin\rho\right]} \tag{6.5}$$

where N is used to denote the number of pixels on the detector. Assuming at this point that sub-pixel interpolation is not used, the range resolution (Δz) can finally be derived from equation 6.5:

$$\Delta z = z(p - 1/2) - z(p + 1/2) \tag{6.6}$$

6.3 Considerations for Underwater Operation

In section 6.2, we considered that the laser was propagating in a medium of uniform refractive index. In this project though, the emission and collection optics are enclosed in a watertight housing filled with air while the propeller blade is submerged in seawater. Since the optical path is a function of the refractive index, the field of view of the collection optics is reduced from FOV to FOV_{uw} (see Figure 4). Accordingly, DOF and S become DOF_{uw} and S_{uw}. Note that the effect of the non-homogeneous refractive index on the emission optics can be neglected as long as the emission optics window is perpendicular to the projection axis.

Thus, to make use of the equations 6.4 to 6.6, equations relating the underwater standoff (S_{uw}) and depth of field (DOF_{uw}) to their open-air counterparts must be derived. Assuming that the collection optics window is perpendicular to the optical axis and that its thickness can be neglected, the relationship between FOV and FOV_{uw} can be derived from Snell's law of refraction. Hence,

$$FOV_{uw} = 2 \cdot \arcsin\left[\frac{\sin(FOV/2)}{n}\right] \tag{6.7}$$

where n is the relative refractive index between seawater and air. By inspection of Figure 4, it can be shown that

$$S = \frac{b}{\tan(\theta + FOV/2)} \tag{6.8}$$

and

$$DOF = \frac{b}{\tan(\theta - FOV/2)} - S \tag{6.9}$$

Equations 6.8 and 6.9 are best solved numerically for various values of b. The corresponding values of θ and FOV can then be computed:

$$\begin{aligned} \theta &= \arctan\left[\frac{2b + DOF_{uw} \cdot \tan(FOV_{uw}/2}{2S_{uw} + DOF_{uw}}\right] \\ 0 &= A \cdot \cos\theta - B \cdot \sin\theta + C \end{aligned} \tag{6.10}$$

where

$$\begin{aligned} A &= b \cdot \cos(FOV/2) \cdot \cos(FOV_{uw}/2) - S_{uw} \cdot \cos(FOV/2) \cdot \sin(FOV_{uw}/2) \\ B &= b \cdot \cos(FOV/2) \cdot \sin(FOV_{uw}/2) + S_{uw} \cdot \cos(FOV/2) \cdot \cos(FOV_{uw}/2) \\ C &= e \cdot \sin\left[(FOV_{uw} - FOV)/2\right] \end{aligned}$$

with e defined as the optical axis distance from the principal point to the window of the collection optics.

Once θ and FOV have been computed, S and DOF are derived from 6.8 and 6.9 for specific values of b. These values can finally be introduced in the triangulation expressions obtained in section 6.2.

6.4 Optimal Configuration

The system's optimal design parameters obtained from the above method are summarized in Table 3.

Table 3: OLDS optimal triangulation parameters

Parameters	Value
Standoff (S)	**2089 mm**
Underwater standoff (S_{uw})	2200 mm
Depth of field (DOF)	**1497 mm**
Underwater depth of field (DOF_{uw})	1100 mm
Baseline (b)	**390 mm**
Effective focal length (f')	249 mm
Triangulation angle (θ)	**8.4 °**
Field of view (FOV)	4.4°
Underwater field of view (FOV_{uw})	**3.3°**
Scheimpflug angle (ρ)	-26.5°
Detector physical length (L)	**25.6 mm**
Number of pixels on the detector (N)	512
Window's distance (e)	**132.5 mm**
Seawater refractive index (n)	1.34

7 OLDS Design

This section describes the overall design of the OLDS. Owing to the system's complexity, it is further subdivided into subsections, each directed towards a specific aspect of the design.

7.1 Systems Engineering

The availability of detectors and laser sources are the first design aspects to consider. Once the detector and laser types have been determined, we can then calculate the signal-to-noise ratio (SNR) for a specific source power.

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Seven major factors influence the collected power at the detector:

1. laser source power;
2. optical integration time;
3. attenuation due to lens and filters in the emission and collection optics;
4. attenuation through water;
5. target reflectivity;
6. angle between the line of sight and the vector normal to target surface;
7. collection optics size.

Aside from these major contributors, other factors also influence the amount of energy collected. Laser beam size and intensity distribution are examples of such secondary factors. These factors can nevertheless be omitted from the analysis calculations without significantly impairing the validity of the results.

7.1.1 Light Propagation in Water

Attenuation through water obeys an exponential law. The energy incident on the blade is given by

$$P_i = \Phi \cdot e^{-c(\lambda)r} \tag{7.1}$$

where Φ is the total power radiated by the laser and r is the source to target distance.

In turn, the power reflected back into any given direction depends on the target's inherent reflectivity. It is also a function of the angle θ between the line of sight and the vector normal to the illuminated region of the blade. A common measure for this directional reflectivity is the bi-directional scattering distribution function (BSDF). Its formal definition is

$$BSDF = \frac{S_F}{\cos\theta} = \frac{P_s}{P_i \cdot \Omega_s \cos\theta} \tag{7.2}$$

where the i and s subscripts mean incident and scattered, respectively, and where Ω stands for the solid angle. Thus, the BSDF is a measure of the ratio of incident to scattered power in a given direction, per unit of projected solid angle. The BSDF is expressed in sr^{-1}. For historical reasons, the BSDF is divided by a $\cos\theta$ factor (related to the apparent size of the spot as viewed from angles away from the normal to the surface). When this term is dropped, we obtain the Cosine Corrected BSDF or scatter function $S_F(\theta)$. To obtain the amount of power reflected back into any given direction, all that is needed is a knowledge of the incident power and of the solid angle subtended by the receiver optics.

If we further note that the total power collected by the detector is attenuated by an exponential factor on its way back and also depends on the collecting optics size, which subtends a solid angle Ω_s, the total power incident on the detector becomes

$$P_r = \Phi \cdot e^{-c(\lambda)r} \cdot S_F(\theta) \cdot \Omega_s \cdot e^{-c(\lambda)r} \tag{7.3}$$

When the transmission of the optics (lens, windows, filters, etc.) and the integration time are further taken into account, the amount of energy (E) incident on the detector becomes

$$E = \Phi \cdot e^{-2c(\lambda)r} \cdot T_{opt} \cdot S_F(\theta) \cdot \Omega_s \cdot \delta t \tag{7.4}$$

Finally, noting that the solid angle Ω_s is equal to

$$\Omega_s = \frac{A_{rec}}{r^2} = \frac{\phi_{lens}^2}{4r^2} \tag{7.5}$$

we obtain

$$E = \frac{\Phi \cdot T_{opt} \cdot S_F(\theta) \cdot \phi_{lens}^2 \delta t}{4r^2} e^{-2c(\lambda)r} \tag{7.6}$$

With the exception of the scatter function $S_F(\theta)$ and the extinction coefficient $c(\lambda)$, all the parameters in equation (7.6) can easily be assigned a value.

The scatter function $S_F(\theta)$ has been measured with a scatterometer for two commonly used blade materials and surface finishes. These measurements have been presented in a feasibility study previous to this project. Briefly, the results of these measurements say that, provided the blade surface is sandblasted, the scatter function value is close to 0.2 and is relatively independent of the viewing angle up to an angle of 45°.

Among the optical properties of water, the absorption $a(\lambda)$ and scattering $b(\lambda)$ coefficients are of the greatest importance since both tend to reduce the amount of light available on the detector. The spectral extinction coefficient $c(\lambda)$ is defined as

$$c(\lambda) = a(\lambda) + b(\lambda) \tag{7.7}$$

where the absorption, scattering and extinction coefficients are expressed in m^{-1}. Consequently, the spectral extinction coefficient can be used to predict the amount of light transmitted through a water column. To obtain an estimate of the extinction coefficient, the operating wavelength must be specified.

In addition to water absorption, the detector spectral sensitivity and the availability of laser sources must also be taken into account. Solid state silicon (Si) detectors are a natural choice. They have a peak sensitivity in the 800 to 900 nm region. However, the seawater absorption is lowest around 450 nm. The combined effect of these two parameters results in optimal overall response in the 450 to 550 nm range (see Figure 5). The detectors used are Hamamatsu (model S3902) 512-pixel linear PDAs.

When the availability of laser sources is finally taken into account, 100 mW frequency-doubled Nd-YAG 532 nm (green) lasers appeared to represent the overall best choice. These lasers were supplied by B&W Tech. At this wavelength, a fairly good estimate for the extinction coefficient of seawater is about 0.25 m^{-1}.

7.1.2 Signal-to-Noise Ratio Calculation

If we assume here that the blade is made of bronze and that the target blade surface region is sandblasted, equation (7.6) can be used to calculate the power incident on the detector. We already know that:

- the value of $S_F(\theta)$ is roughly around 0.2;
- the maximum distance between the emission/collection optics and the blade is about 3.3 m; and
- the extinction coefficient of seawater is about 0.25 m^{-1}.

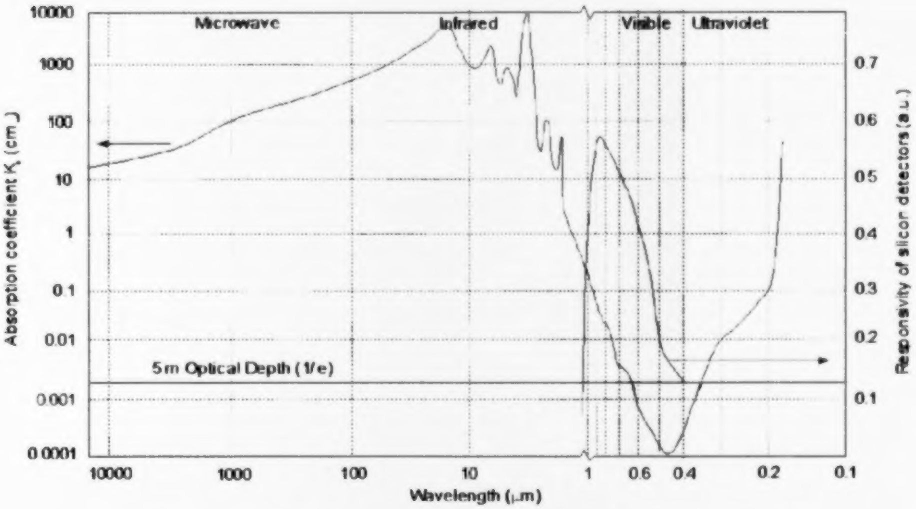

Figure 5: Absorption spectra of seawater and SI detectors responsivity

Because of loss in the laser-to-fibre coupling and attenuation inside the fibre, the total power radiated by the laser (Φ) does not correspond to the entire 100 mW laser power. Experiments have shown that about 50 percent of this power is lost or attenuated so that the total power radiated by the emission optics is (Φ) is about 50 mW. The transmissivity (T_{opt}) of the optics can be estimated to be roughly around 0.3. This value takes into account the optical loss over all windows, lens, and filter.

We finally find that the amount of energy (E) incident on the detector over a 1 ms period and for a 75 mm collection optics diameter is

$$E = 7.4 \times 10^{-11}\,\mathrm{J} \tag{7.8}$$

To perform sub-pixel interpolation, the system is designed so that the image of the circular beam spot on the blade covers around 8 pixels on the detector. If we assume that the laser beam spot intensity on the blade is constant over the surface, the energy incident on a single pixel is 7.4×10^{-11} J × 1/8 ≈ 9.3 pJ. The amount of electrical charge stored on a single pixel can then be determined by taking into account the detector quantum efficiency η at the operating wavelength. At 532 nm, silicon-based PDAs exhibit an absolute sensitivity of about 0.32 A/W (C/J). Therefore, the integrated charge (Q) on a single pixel is

$$Q = 9.3\,\text{pJ} \times 0.32\,\text{C/J} = 3.0\,\text{pC} \tag{7.9}$$

or 30 percent of the saturation charge of the Hamamatsu S3902 PDA.

Assuming that the system noise figure is mostly limited by the detector rather than by the post-processing electronics, and neglecting the optical background noise (due to ambient light entering into the system), the SNR can be evaluated by calculating the detector dark current shot noise. For the Hamamatsu S3902 PDA, the shot noise at 20°C is about 2 pA. For a 1 ms integration time, the accumulated charge is then 2 fC and the SNR becomes

$$SNR = \frac{3.0\,\text{pC}}{2\,\text{fC}} = 1500 \tag{7.10}$$

If we were to reduce this figure by an order of magnitude (to account for neglected optical losses and extraneous electronic noise), we would still be left with an SNR of ~150, which is considered large enough to attain the 1 mm displacement resolution sought.

7.1.3 Integration Time and Resolution Blurring

The problems addressed in this section derive from basic geometrical considerations. Since the blade is rotating while the range image sensor is fixed, the laser spot describes an arc of a circle on the blade surface. Thus, when the pitch is close to zero, the blade movement in the X-axis relative to the laser spot is given by

$$x_{rot} = 2\pi r\omega \cdot \delta t \tag{7.11}$$

where ω is the angular speed of the propeller and r is the propeller radius at which the blade displacement is being measured. If the range imaging system points at the 0.9 R, then for a 15-foot diameter propeller rotating at a nominal speed of 120 rpm, we have x_{rot} = 29 mm for a 1 ms integration time. Consequently, the depth measurements are averaged over a 29 mm width. When the blade pitch is not set to zero, the X-axis movement is accompanied by a corresponding Z-axis movement of the spot approximately given by

$$z_{rot} = x_{rot} \tan\theta_{pitch} \tag{7.12}$$

At the maximum 35° pitch angle, z_{rot} would be 20 mm or 20 times the targeted resolution of 1 mm.

A first consequence of a too long integration time is that it introduces a convolution of the Z-axis coordinate of the region being interrogated with the blade profile over that region. Fortunately, *a priori* knowledge of the blade shape permits the removal of this side effect from the measurement. A second consequence of a too long integration time is a blurring of the laser spot image on the detector that will tend to reduce the contrast.

There are two ways of dealing with these issues. The first solution involves a reduction of the detector integration time. This solution is not applicable for the selected Hamamatsu detector. This detector does not support exposure control or any kind of electronic shutter.

The second solution would be to use laser modulation. Laser modulation allows the emission of short laser pulses that reduce the integration time and then the related blade movement. The laser drivers used support modulation within a range of 10 to 90 percent duty cycle. This means a laser pulsed range from 0.1 ms to 0.9 ms.

Of course, the use of modulation reduces the overall SNR. For instance, if a 10 percent duty cycle is used, the SNR must be multiplied by the same percentage since it has been calculated for a 1 ms integration time. We then obtain SNR = ~15.

7.2 Opto-Mechanical Engineering

The opto-mechanical design of optical head assemblies takes into account such factors as components registration, modularity, robustness and stability. Optical ray tracing and analysis of aberrations are parts of the optical design process while mechanical positioning of the optical elements relative to one another are discussed in opto-mechanical design.

7.2.1 Emission Optics Design

The purpose of the emission optics is to project the laser energy along the laser line of sight of each channel. Since the laser units are located within the shipboard controller, the laser energy is first injected into fibres using Melles-Griot laser-to-fibre couplers (model 09LFM001). The fibres are FC connected to these couplers.

The laser energy of each channel is transferred to the underwater subsystem through a fibre-optic cable. A three-lens assembly is used to collimate the laser beam coming out the fibre. The first design step was to choose an effective combination of fibre core diameter and fibre numerical aperture (NA). The NA affects the overall size of the system as well as the DOF, while the core diameter has an impact on the injection efficiency and the spot size on the blade. The fibre selected is multimode and has a core diameter of 50 µm with an NA of 0.20. A 300-ft. fibre-optic cable of four of those fibres is used (one for each channel and one spare). This is a military spec FO cable manufactured by Optical Cable Corporation (model D04-070C-A3FB/1FC/900-MIL).

Once the fibre was selected, the spot sizes obtained with various collimator focal lengths were compared at a number of distances ranging from 2.2 to 3.3 m. An effective focal length of 45 mm was selected in favour of its smaller spot size at 3.3 m. A two-element optical system consisting of a meniscus lens and a bi-convex lens was first optimized. From these values, the system was optimized again to take advantage of commercially available lenses. The final design uses three lenses and produces a 3.2 mm (FWHM) spot size at mid range (2.75 m). Figure 6 and Table 4 show the resulting emission optics design and components.

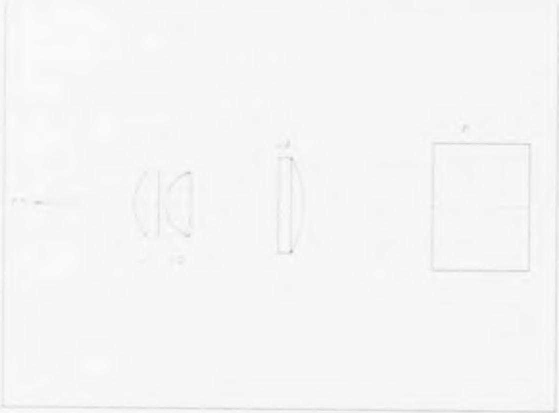

Figure 6: Emission optics design

Table 4: Emission optics design components

Part	Description	Focal length	Diameter
L1	Plano-convex lens	15 mm	10 mm
L2	Plano-concave lens	-10 mm	10 mm
L3	Plano-convex lens	30 mm	15 mm
F	Lexan window	-	-

7.2.2 Collection Optics Design

The collection optics collect the energy diffusely reflected by the blade surface. Obviously, larger entrance pupil diameters result in higher signal levels as more energy is collected from the larger solid angle subtended by the receiver. Two practical issues nevertheless limit the diameter. First, larger lenses are more costly and less readily available. Second, larger entrance pupil sizes require larger and thus thicker windows. Larger windows are more susceptible to breakage and introduce transmission losses. These limitations lead us to select a pupil size of 76.2 mm.

Small adjustments to the baseline were made until the resulting effective focal length could be designed from off-the-shelf lenses. The completed design is based on a triplet with an effective focal length (f') of 249 mm. When the detector is tilted by the proper Scheimpflug angle, good focussing on the detector is obtained for distances ranging from 2.2 m to 3.3 m. Aberrations were well corrected for the required field of view. As a last requirement, the assembly height had to be minimized. This requirement was dictated by the fact that the underwater housing has to present the slightest grip to ice as possible. To meet that requirement, the optical path of the collection optics is folded using a flat mirror. Figure 7 and Table 5 show the resulting collection optics design and components.

Figure 6: Emission optics design

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Figure 7: Reception optics design

Table 5: Collection optics design components

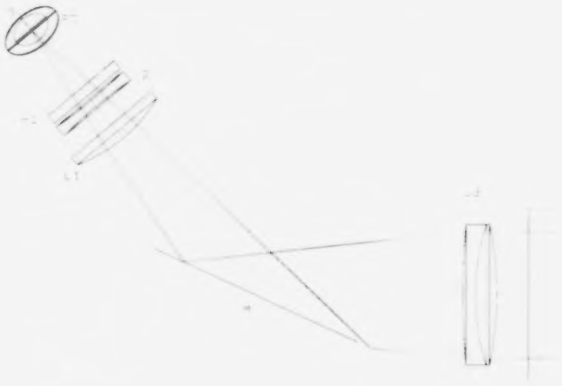
Part	Description	Focal length	Diameter
D	Detector array	-	-
FD	Detector window	-	-
L1	Plano convex lens	175 mm	75 mm
L2	Bi-concave lens	-250 mm	50 mm
L3	Doublet lens	300 mm	82 mm
FI	Interferencial filter	-	50 mm
M	Plane mirror	-	-
F	Lexan window	-	-

7.2.3 Opto-Mechanical Design

This section describes the opto-mechanical design of the emission and collection optics. All the mechanical components had to be compact, offer proper corrosion resistance and be very rugged to ensure stability of all optical alignments.

Emission Optics

The purpose of the emission channel is to collimate the laser beam coming out of the optical fibre. This is achieved with three lenses. As shown in Figure 8, those lenses are placed in two independent barrels and then in the main housing that supports the fibre connector. This arrangement enables the axial position of the first and second barrel to be adjusted relative to the fibre connector to optimize the divergence of the laser beam.



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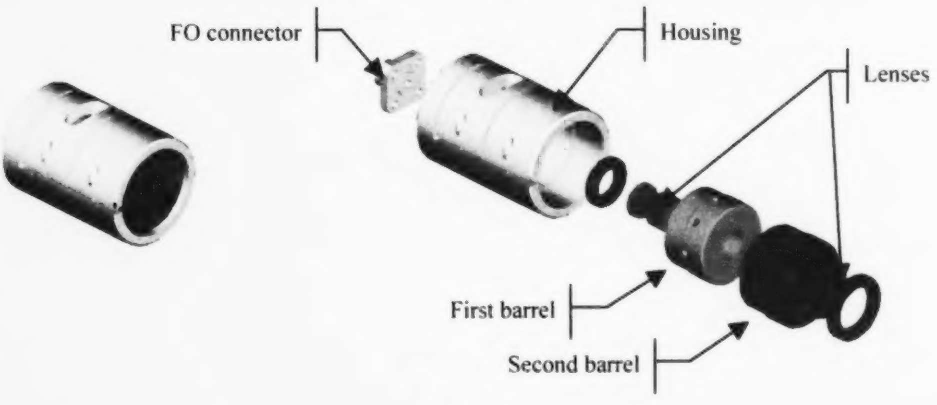


Assembled view **Exploded view**

Figure 8: Emission optics assembly

Once the adjustment is done, everything can be locked in place. This gives a very rugged and compact system that measures 1.25" in diameter and 1.75" in length. Anodized aluminium was used for all parts for its low weight, corrosion resistance and high machining properties.

Collection Optics

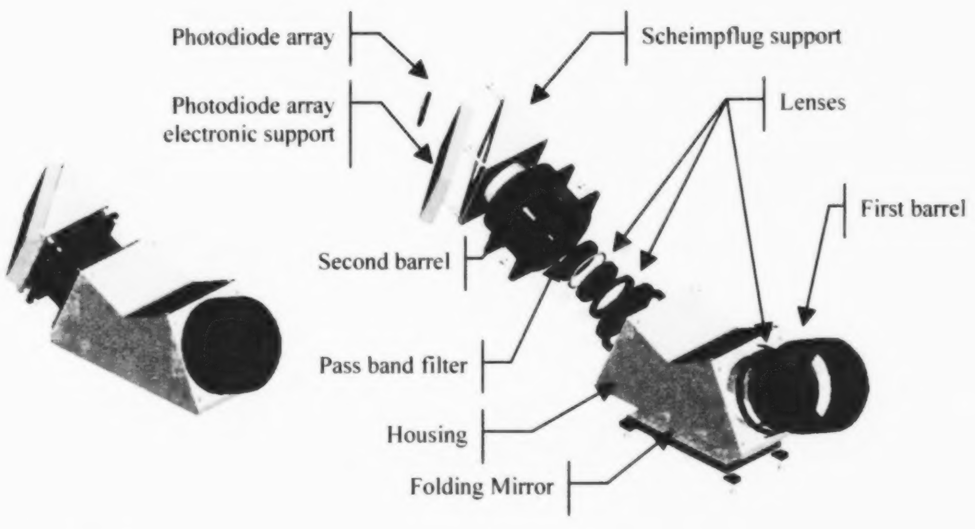
The collection optics enable the laser energy reflected by the propeller to be collected and focussed onto the photodiode array. To achieve this, three lenses and a pass band filter are used. Figure 9 shows the first lens located in the first barrel and the other two lenses and the filter located in the second barrel. The two barrels are attached to the housing, which also supports the folding mirror. That mirror was introduced to minimize the height of the assembly since the elevation angle of the optical axis had to be approximately 25°. Mechanical dimensions had to be very tight to respect the positioning tolerances of the optical components without any adjustments.

The only adjustments in the system are for the PDA and are provided by the Scheimpflug and PDA supports for the axial and lateral directions, respectively. Again, when the energy is maximized on the PDA through these adjustments, everything can be locked in place. It is important to note that the Scheimpflug support angle is fixed at 35.1°.

The result is a compact and rugged system. Its external dimensions are 5.7" in height, 3.9" in width and 14.5" in length. Again, anodized aluminium was used for all parts for its low weight, corrosion resistance and high machining properties.

7.3 Signal Conditioning, Processing and Electronics

This section describes the implementation of detection electronics, data acquisition and data processing to achieve the reference system target specifications. Each aspect is discussed separately.



Assembled view **Exploded view**

Figure 9: Collection optics assembly

7.3.1 Underwater Subsystem Electronics

The underwater subsystem electronics (see Drawing EDS0153 - page 1 of 2 - in Appendix A) are composed of five electronic circuits: one DC-DC conversion circuit, one signal generation circuit, and three detection electronic circuits (one for each detection channel).

DC-DC Conversion Circuit (Drawing EDS0158 in Appendix A)

The underwater subsystem is powered with a 30 V DC supply. It first includes power DC-DC conversion circuitry to generate the DC voltages required by the various electronics. The DC-DC conversion is performed with two PICO (model FA15S) converters, one for +15 V and the other for the -15 V. These voltages are transmitted to the signal generation circuit.

Signal Generation Circuit (Drawing EDS0151 in Appendix A)

The underwater subsystem electronics also include a signal generation circuit. This circuit generates the 4 MHz master clock and different phase signals required by each detection circuit. The clock and phase signals as well as the +15 V and -15 V voltages are fed to the three detection circuits using a common control bus.

This circuit also converts the transistor-transistor logic (TTL) master clock signal into a video level signal to allow the master clock to be transmitted to the shipboard subsystem. The signal generation circuit hosts different power supply connectors for other components such as the video camera and the data transport equipment.

Detection Electronics Circuit (Drawing EDS0150 in Appendix A)

Each detection channel has its own electronic circuit mounted to its reception optics assembly. The detection of the position of maximum intensity on each channel is achieved using a Hamamatsu (model S3902) 512-pixel linear PDA driven by the signal generation electronics (see Figure 10).

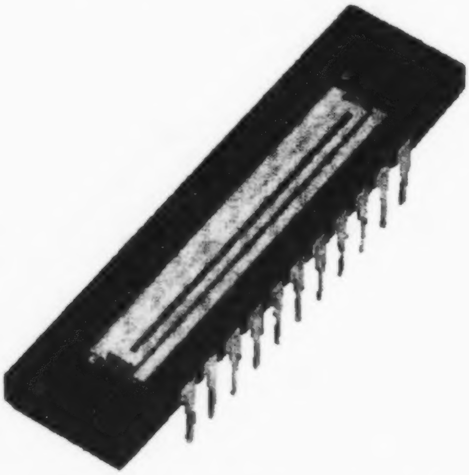


Figure 10: Hamamatsu S3902 linear photodiode array

The detection electronics circuit also acts as a signal conditioner for the analog. The signal produced by the PDA is first amplified, after which it is fed to a linear phase filter to preserve the peak shape. Since the strength of the signal varies as the blade rotates (the point of intersection of the blade with the laser beam recedes as a result of the blade rotation), an automatic gain control amplifier controls the signal level to reduce the dynamic excursions. The analog signal is then sent to the shipboard subsystem using the data transport equipment.

The PDA line rate is set at 1 kHz so that 1000 range values per channel are outputted every second. At the end of each line scan, an end-of-scan (EOS) TTL signal is sent by each detection electronics circuit. One of them (selected with a jumper) is sent to the signal generation circuit, which forwards it to the shipboard subsystem. This signal is used to synchronize the detection with the laser modulation and with the data acquisition.

7.3.2 Shipboard Subsystem Electronics

The shipboard subsystem electronics (see Drawing EDS0153 - page 2 of 2 - in Appendix A) are located inside the OLDS shipboard controller and comprise two electronic circuits, a signal conditioning and laser modulation circuit and a shipboard controller AC cabling circuit. The shipboard controller also hosts three laser units (heads and drivers) and six data transport fibre-optic (FO) transceivers.

Signal Conditioning / Laser Modulation Circuit (Drawing EDS0152 in Appendix A)

Once the three detection signals reach the shipboard instrumentation, they are sent to a conditioning circuit composed of three low-pass filters tuned to a cutoff frequency of 70 kHz. The filtered signals are then sent to the data acquisition board located inside the OLDS computer.

This circuit is also responsible for the modulation of the lasers. The modulation of each laser can be adjusted separately from duty cycle settings varying between 10 and 90 percent. A 10 percent duty cycle means the laser is on 10 percent of the time during a 1 ms acquisition period. This means the integration time can be set from 0.1 ms to 0.9 ms on each channel. Although the integration time can be different for each channel, the modulations of all channels are synchronized with the EOS signal coming out from the selected detector.

The shipboard signal conditioning and laser modulation circuit has a bipolar gain switch used to modify the gain setting on all three underwater detection electronics circuits. The gain factor can be set to 1 or 10. The gain setting signal is transmitted to the underwater detection electronics circuits using the data transport equipment. This circuit hosts the different power supply connectors for the data transport equipment.

Shipboard Controller AC Cabling Circuit (Drawing ECA0011 in Appendix A)

The OLDS shipboard controller is powered with a 120 V AC supply. The AC line is switched in using a panic button located on the front panel of the controller and then distributed to the AC-DC converters, laser drivers and fan units. When the panic button is activated, no power is sent to any shipboard or underwater components.

Two AC-DC converters are used. The first one is a ±12 V DC converter used for shipboard circuits and data transport equipment. The second one is 30 V DC converter used exclusively for underwater instrumentation.

7.3.3 Data Acquisition and Processing

Once filtered inside the shipboard controller, the three detection signals as well as the clock and trigger (EOS) signals reach the data acquisition board. Once digitized, the three signals are sent to the data processing board responsible for the peak detection and range calculations. The data acquisition and processing boards are located inside the OLDS computer.

Data Acquisition

The data acquisition is a Grabber44 three-channel high-speed digitizer board made by Innovative Integration. This board can digitized up to 40 million 12-bit samples per second on three different channels in parallel. Each channel uses a Burr-Brown analog-to-digital (A/D) converter (model ADS800) and all three channels are synchronized together using common external 4 MHz clock and 1 kHz trigger (EOS) signals provided by the underwater subsystem electronics. The data acquisition board is mounted on the data processing board using a TIM40 slot.

Data Processing

The data processing is provided by a PCI44 C44 digital signal processing (DSP) board also supplied by Innovative Integration. It is installed on the PCI bus of the OLDS computer. The data processing implemented on the DSP is mainly a peak detection algorithm based on a finite-impulse filter (FIR) followed by a zero-crossing detection (see Figure 11). The 16 highest peak values above a certain threshold are sent to the FIR and to the zero-crossing detector for sub-pixel range calculation. For each channel, this range value, the 16 peak values and their corresponding starting index are all stored in a binary format file. If we add a timestamp value for all three channels, we get a total of 55 values per second to store for all three channels.

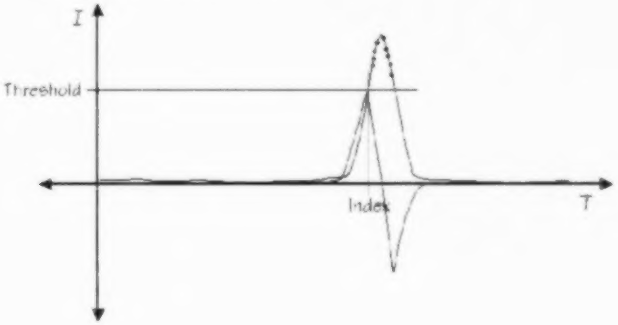


Figure 11: Peak detection process

Timestamp Generator

As mentioned previously, an identical timestamp value is assigned to each sample. The timestamp value is needed for post-synchronization with the peripheral independent variables (PIVs) recorded on a second computer. In fact, the timestamp is sent to this computer and recorded as other PIV signals. The generation of the timestamp signal is made by an industry pack (IP) mounted on an IP site of the PCI44 DSP board. The industry pack is an IP-ADIO supplied by Green Spring Computer. The timestamp signal itself is a square wave analog signal with variable amplitude and period.

OLDS Computer

In terms of hardware, the OLDS computer is a Teknor PCI-935 single board industrial computer mounted on a passive backplane (model PCA-6108P3). This computer has a 200 MHz Pentium Pro CPU with internal SCSI, video and Ethernet controllers. The passive backplane is installed inside an IPC-610 Industrial Computer chassis holding CD-ROM and floppy drives as well as a removable SCSI hard-disk slot. Since there is a considerable amount of processed data to gather, several removable SCSI hard disks are used.

In terms of software, the OLDS computer runs on a Microsoft Windows NT 4.0 operating system. The compiler used is Microsoft Visual C/C++. A GO-DSP JTAG code emulator/debugger is also used. INO's internally developed software is used for data processing and visualization.

7.4 Umbilical Link

The underwater and shipboard subsystems are linked together with an umbilical conduit composed of emission fibres, data and control signal fibres, a power supply line, and a dry-air supply line. The umbilical link itself is a 300 ft. Urebrade conduit manufactured by Newage Industries. The conduit is made of PVC and has an internal diameter of 3/4".

7.4.1 Data and Control Signals

Data and control signals transport between the underwater and the shipboard subsystems are sent through FO communication links. Six FO links are needed for seven different signals:

1. Channel 1 analog signal
2. Channel 2 analog signal
3. Channel 3 analog signal
4. Master clock analog signal
5. Video camera analog signal
6. Trigger (EOS) TTL signal
7. Amplification gain TTL signal

The first five analog signals are sent using FM FO transceivers pairs made by FORCE. Transmitters (model 2768-T-0-MBST) are located in the underwater enclosure and receivers (model 2768-R-0-BGST) in the shipboard controller chassis. The last two TTL signals are sent using a bi-directional FO transceivers pair made by Litton Poly-Scientific (model FO46-17). The trigger (EOS) signal is sent from the underwater enclosure to the shipboard subsystems while the amplification gain signal travels in the opposite direction. Both use the same fibre and transceivers pair since this link is bi-directional.

All communication fibres are multimode and have a core diameter of 62.5 µm with an NA of 0.275. A 300 ft. FO cable of six of those fibres is used. This is a military spec FO cable manufactured by Optical Cable Corporation (model D06-085C-W3SB/1UC/900-MIL).

7.4.2 Power Supply Line

The conduit also includes the power supply line for the underwater subsystem. This line is a 300 ft. electric cable composed of three #18 conductors. The cable has an outer diameter of 0.24" and is manufactured by Essex (cat. no. 461831). Two of the cable conductors are used for ground and the third one has the 30 V DC reference voltage for the PICO DC-DC converter.

7.4.3 Dry-Air Supply Line

The umbilical link includes 300 ft. of a 1/4" external diameter polyethylene conduit. This small conduit is used for the supply of dry air inside the underwater enclosure to prevent water condensation. The ship's compressed air system is used as an air supply but this air must be dried using a desiccant dryer made by Compair (model DD30-4). Oil and particulate filters also made by Compair are used to make sure the supplied air is free of any substance or particulate. Finally, a regulator is used to maintain the pressure inside the underwater enclosure around 7.5 psi. Figure 12 shows the air dryer, filters, regulator and gauge.

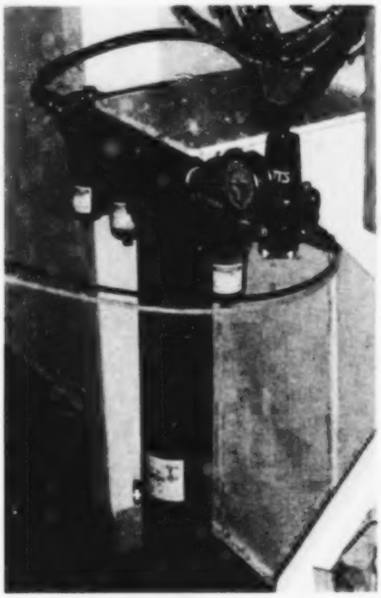


Figure 12: Desiccant dryer, oil and particulate filters, pressure regulator and gauge

7.5 Shipboard Subsystems Packaging

The OLDS shipboard controller hosts the two shipboard subsystem electronics circuits, an AC-DC power supply, three laser units (heads and drivers) and six data transport FO transceivers, which are assembled in a rugged chassis that resembles a standard rackmount unit (see Figure 13).

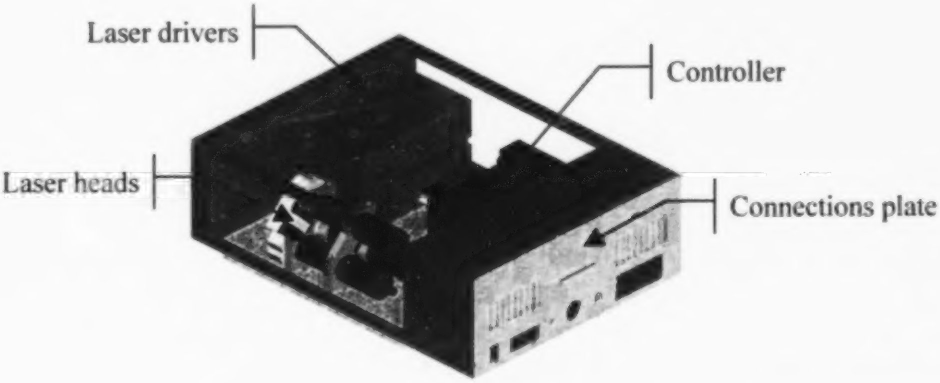


Figure 13: Shipboard subsystem controller chassis (cover off)

The shipboard controller also hosts various switches on the front and back panels. On the front panel, three rotary switches are used to individually adjust the duty cycle (modulation period) of each laser. Duty cycles from 10 to 90 percent in increments of 10 percent can be selected on the fly. Another binary switch is used to select the desired gain on the detection electronics. This gain can be 1 or 10. The front panel also has a push-button switch used for emergency shutdown. When this button is pushed, all the power is turned off including the lasers and the electronics components circuitry. The back panel has only a main AC power switch, which has the same effect as the emergency pushbutton.

The components inside the shipboard controller are located so that all connections can be made easily. These connections include optical fibres, electric cables and the dry-air conduit. The front panel of the shipboard controller can be removed to facilitate the connections of the emission fibre optics.

7.6 Procurement of Components

A tremendous number of components have been used in all aspects of the development and prototyping of the OLDS. The procurement itself started in February 1997 and ended in October 1999. The main items and their suppliers are listed in Table 6.

Table 6: OLDS prototype main components and suppliers

Component	Supplier / Manufacturer
Industrial PC	**MICS**
Windows NT 4.0 OS	Microsoft
Data acquisition and DSP board	**Technolor / Innovative**
Industry Pack for DSP board	Technolor / Greenspring
Seawater tank for test-bench setup	**Letan Acry-Formes**
Photodiode arrays	Hamamatsu
TTL fibre-optic transceivers	**Litton Poly-Scientific**
FM video transceivers	White Radio / FORCE
Lasers and driver units	**B&W Tek**
Security glasses	Guillevin International
Lens	**JML Optics**
Lens	Spindler Hoyer
Lens	**Melles-Griot**
Lens	Edmund Scientific
Fibre-optic connectors	**Semad / Hirose**
Fibre-optic connectors	Thorlabs
Fibre-optic connectors	**FIS / Molex**
Laser-to-fibre couplers	Melles-Griot
Fibre-optic cables	**Nedco**
Desiccant air dryer and filters	Compair
PVC Urebrade conduit	**Thorburn**
Polyethylene conduit	Pneutech
Electric cable	**Anixter / Essex**
Lexan plate for windows	Rematech
Electronic components	**Future Electronique**
13 GB hard drives	PC-Tronic / Quantum
DC-DC converters	**PICO Electronics**

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Lens	Spindler Hoyer
Lens	**Melles-Griot**
Lens	Edmund Scientific
Fibre-optic connectors	**Semad / Hirose**
Fibre-optic connectors	Thorlabs
Fibre-optic connectors	**FIS / Molex**
Laser-to-fibre couplers	Melles-Griot
Fibre-optic cables	**Nedco**
Desiccant air dryer and filters	Compair
PVC Urebrade conduit	**Thorburn**
Polyethylene conduit	Pneutech
Electric cable	**Anixter / Essex**
Lexan plate for windows	Rematech
Electronic components	**Future Electronique**
13 GB hard drives	PC-Tronic / Quantum
DC-DC converters	**PICO Electronics**

8 Test Bench

To test the various components and their interaction under both static and dynamic conditions, and to perform calibration, a test bench had to be designed. The key component of this experimental setup is an acrylic pool, depicted in Figure 14. The pool is 3.6 m long and 300 mm high, while its width varies from a minimum of 300 mm up to a maximum of 860 mm. The irregular shape was dictated by the desire to minimize the weight of the filled pool. The pool is filled with 513 L of artificial seawater whose refractive index is maintained at 1.34.

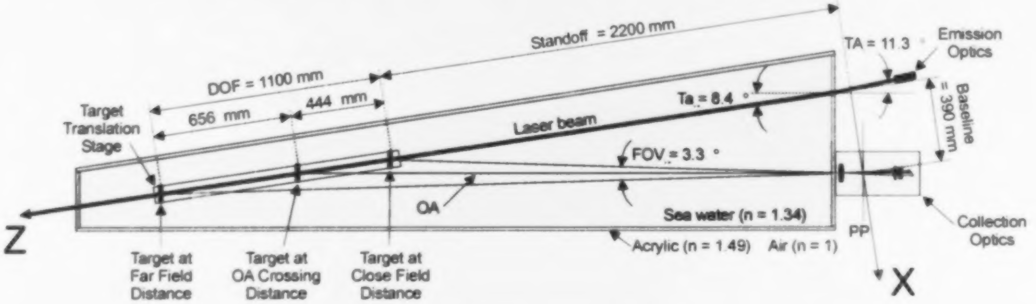

Standoff = 2200 mm
TA = 11.3 °
Emission Optics
DOF = 1100 mm
444 mm
656 mm
Target Translation Stage
Ta = 8.4 °
Baseline = 390 mm
Laser beam
FOV = 3.3 °
OA
Sea water (n = 1.34)
Acrylic (n = 1.49)
Air (n = 1)
PP
Collection Optics
Z
X
Target at Far Field Distance
Target at OA Crossing Distance
Target at Close Field Distance

Figure 14: Experimental setup

The pool stands on tables with the emission and collection optics of a single OLDS channel located at one end. The emission and collection optics are positioned according to the triangulation geometry. A precision translation stage, hung over the pool, is used to move a blade sample across the whole depth of field. Operation of the setup is pictured in Figure 15.

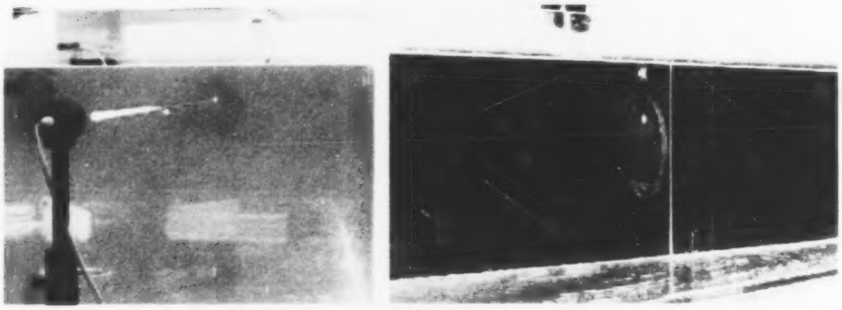


Figure 15: Experimental setup photos showing emission and blade sample

The experimental setup results showed that both static and dynamic measurements obtained with the blade samples at rest and moving indicate a 3σ accuracy of 0.5 mm in the far field. These statistics were derived from a series of seven-second long (7 000 samples) data logs. Figure 16 shows the results obtained in the near (2.2 m), mid (2.75 m) and far (3.3 m) fields.

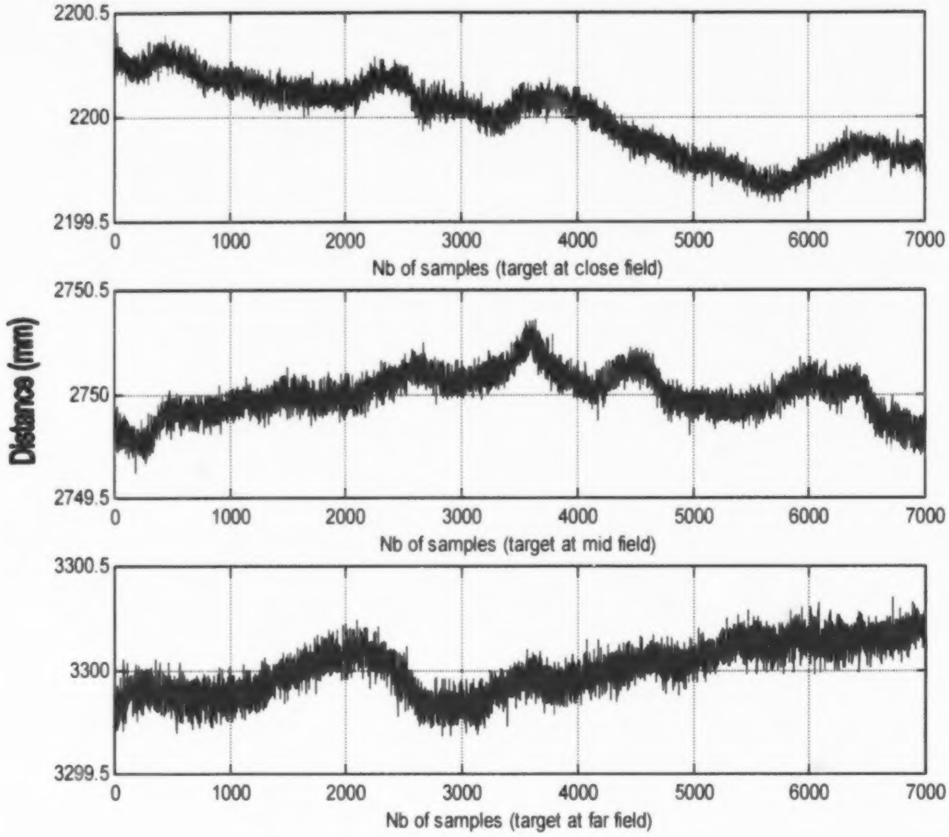


Figure 16: Experimental setup range results acquired at close, mid and far field.

9 OLDS Prototyping

The OLDS is composed of approximately 100 mechanical parts. The watertight housing and the emission and collection optics contain 3/4 of these parts while the shipboard subsystem controller contains the rest.

9.1 General Design Guides

Like any prototype, this system is unique. Also, it had to work properly the first time and adjustments in the field were almost impossible. Through the whole design process, several design guides had to be followed to ensure the success of the project.

Our main concern was with the harsh environment associated with a system submerged in salt water for several weeks attached to the hull of a running icebreaker. Those conditions meant vibrations, shocks, water pressure and temperature around 0°C. The purpose of the design guides was to:

- eliminate moving parts by locking any adjustments and to overdesign any supports and parts associated with ice block collision protection to reduce susceptibility to vibrations and shocks;
- use corrosion-resistant materials for the parts in contact with salt water;
- minimize the number of openings in the watertight housing and to use, when necessary, joints easily installed in the field;
- lock all screws with thread locker or stainless steel wires.

9.2 Materials

All parts are made of 6061-T6 aluminium except for some folded plates made of 1100 aluminium and the watertight housing made of 304L stainless steel. Lexan is used for the windows because it is highly resistant to impact and has good optical properties. Stainless steel offers excellent corrosion resistance against salt water. Almost all of the aluminium parts are black anodized to improve surface hardness and minimize undesired light reflection.

10 Bench-Top Validation

This task involves the bench-top testing of the OLDS in underwater conditions. These tests were planned to be conducted underwater in a specially designed basin. We first thought to use IMD's facilities in Newfoundland, but because of budget limitation and schedule deadline, it was decided to perform this operation at INO in a temporary setup (see Figure 17).

Figure 17: Bench-top validation temporary setup

The temporary setup was composed of a custom-made basin filled with tap water. The underwater package was immerged and sat in this basin so that the emission laser beams could aim at a blade sample target. Since various mechanical and electrical adjustments were necessary during this operation, the two top covers of the package were removed. Very careful manipulations were then required to prevent flooding inside the package.

The main task involved in the bench-top validation was the optical alignment of the detector arrays. Each detector was aligned individually using a blade sample target located at a precise distance from the package. The maximum returned signal on the detector was used as the main criterion of alignment.

The standoff, DOF and FOV were also confirmed at this stage. They were evaluated to correspond approximately to the theoretical values reported in Table 3.

11 Peripheral Instrumentation

The purpose of the peripheral instrumentation is twofold:

- To measure movement and deflections of the propeller shafting that can contribute to the blade deflections observed with the OLDS so that the blade deflection measurements can be compensated for these effects to arrive at the deflections because of blade bending that can be interpreted in terms of ice load;
- To measure and document the operating point of the propulsion plant and steering system and the state of motion of the vessel relative to the surrounding ice cover so that measured blade ice loads can be related to these parameters.

11.1 Peripheral Instrumentation Design

The peripheral instrumentation required for this experiment includes the following subsystems:

- Strain gauge-based propeller shaft torque and thrust measurement system, incorporating radio telemetry to remove these two signals from the rotating propeller shaft (see Figure 18);

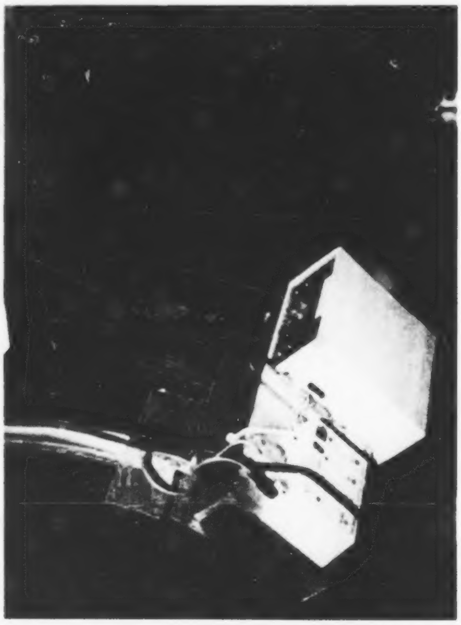


Figure 18: Shaft torque and thrust instrumentation

- Magnetic proximity sensors to measure shaft run out at the stern tube seal as well as axial movement of the shafting at the shaft brake (see Figure 19 and Figure 20):

Figure 19: Proximity sensors to measure shaft runout at stern tube seal

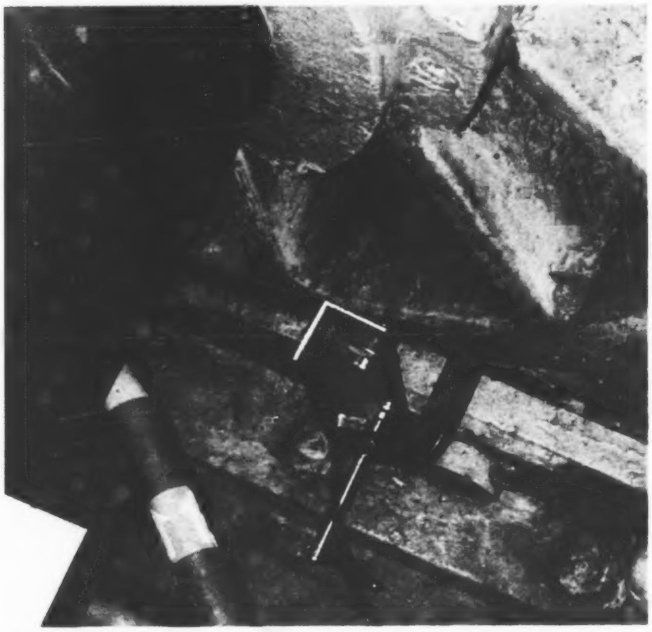


Figure 20: Proximity sensors to measure shaft axial movement

- Magnetic proximity switch pickups in combination with a ferromagnetic encoder band to detect propeller shaft angular orientation (see Figure 21);
- Rudder angle potentiometer to measure angular position of the rudder at the steering gear;
- Six channels of isolation amplifiers to interface the three shaft RPM signals as well as the port motor current and voltage and the port motor field current to the Machinery Data Acquisition System (MDAS).
- MDAS multi-channel A/D PC-based data acquisition system to record all analog output signals from the peripheral instrumentation sensors;
- Digital serial interface to, and computer recording of the output NEMEA navigation sentences from the ship's GPS receiver.

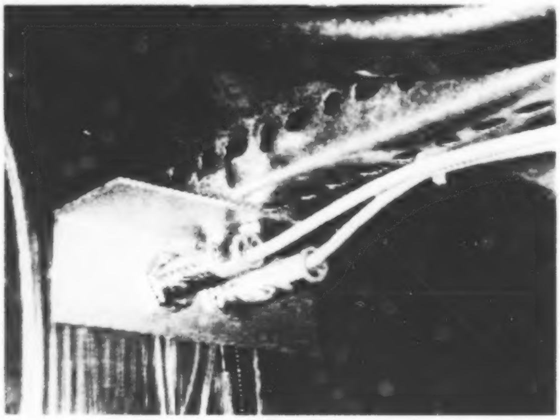


Figure 21: Proximity switches and shaft encoder band

11.2 Over-Side Speed Measurement

The speed and course of the ship over ground can be derived from the vessel's GPS receiver, but as this speed is determined by differentiating a sequence of geo-referenced fixes, each of which can have significant local error, the speed indication only becomes reasonably accurate when averaged over many tens of fixes spread over tens of seconds to a few minutes. During such periods of time the ship's actual speed can undergo significant variations, particularly during icebreaking operations that may involve ramming manoeuvres. Also, the GPS system measures the ship's speed relative to fixed earth coordinates, not relative to the surrounding ice cover, which can have a drift speed as high as about 1.0 kn or more, depending on wind and current conditions.

The ship's speed relative to the surrounding ice cover is an important parameter potentially affecting the frequency and severity of propeller-ice interaction. To measure this speed with good accuracy and with sufficient frequency to be able to correlate it with the ice interactions being measured at the propeller, an over-the-side looking video camera was specified.

A conventional NTSC colour TV camera in a heated environmental housing was specified to be installed on the ship's rail at the level of the main deck looking vertically down over the ship's side at the ice cover next to the hull (see Figure 22). This camera should be situated just at the aft end of the parallel midbody of the hull on the port side, just forward of the location of the port propeller. Two quartz-Halogen flood lamps were specified to be mounted, one on either side of and slightly above the level of the camera to illuminate the ice surface next to the hull in the camera's field of view during hours of darkness.

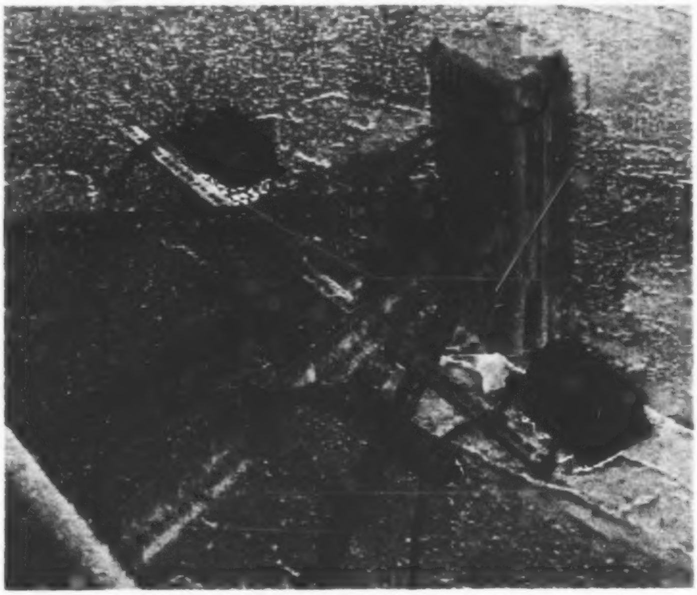


Figure 22: Over-side speed measurement using an outdoor video camera

The camera's output is to be recorded continuously by a conventional VHS videotape recorder while the ship is under way and propeller blade load measurements are being recorded. The video imagery is to be annotated with date and time information from a date-time generator so that the imagery can be correlated in time with the OLDS data acquisition system recordings.

Once the camera is deployed, its field of view must be calibrated at the ice surface by placing a marker of known length, typically 2 m, on the water surface parallel to the side of the ship in the camera's field of view and recording this imagery. This serves to provide a scale for the width of the video's field of view at the sea surface. Thereafter the speed of the ship can be accurately determined over any short span of time by measuring the time required for any ice feature close to the water plane to transit a known distance in the camera's field of view. When analyzing significant ice impact loads at the propeller, the ship's speed relative to the surrounding ice cover can be determined in this way for the short interval of time immediately preceding the impact event.

In addition to providing accurate and relevant speed information, the imagery from this camera can also help to identify significant large ice features that may be passing along the side of the ship and into the instrumented propeller.

11.3 PIV Isolation Amplifiers

Six analog devices (AD 210 J isolation amplifiers) were provided to facilitate the connection of analog outputs from the ship's propulsion control system to the MDAS, which will acquire the PIV signals (see Figure 23).

These isolation amplifiers provide more than 2500 V of three-port isolation, ensuring that no loading effects will be passed back to the ship's control system from the MDAS. They also ensure that all signals derived from the ship's control system float with respect to the MDAS ground, eliminating the possibility of ground loops that could inject noise into the acquired signals.

The six signals to be acquired from the ship's propulsion controls via these isolation amplifiers are:

1. Port shaft speed
2. Centre shaft speed
3. Starboard shaft speed
4. Port motor voltage
5. Port motor current
6. Port motor field current

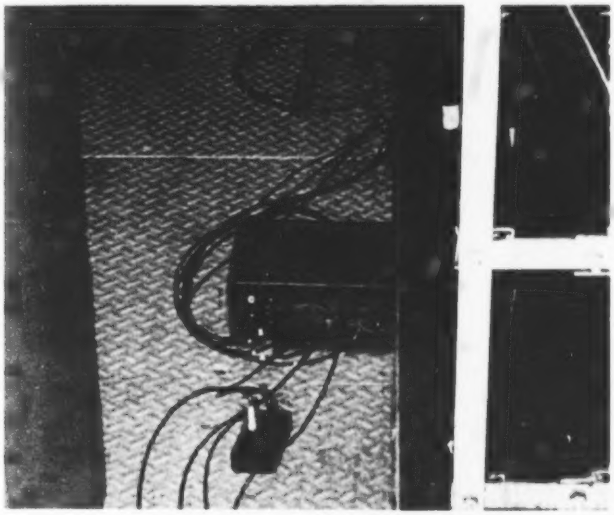


Figure 23: Six-channel isolation amplifier unit in propulsion control centre

12 Data Acquisition System

The shipboard data acquisition system consisted of the following principal subsystems:

- OLDS control unit and data acquisition computer
- MDAS data acquisition computer
- Blade Load Calculation and GPS recording computer

The OLDS acquires blade range data at the rate of 1000 range values per second for each of the three laser ranging channels. A high-speed DSP board in the OLDS data acquisition computer processed the output of each of the three PDAs to determine the location of the maximal output along each array. For each of the three ranging channels, this location, together with the values of the photodiode cell responses for 16 cells spanning the location of the maximum, was written to the output data file once each millisecond.

The MDAS acquired 16 channels of analog sensor information at the rate of 1000 12-bit readings per channel per second from a PC bus A/D data acquisition board.

Both the OLDS and MDAS computers acquired data independently, writing their output data files on local 13 GB removable hard drives.

To provide synchronization of the time bases between the two systems, the DSP board in the OLDS data acquisition computer was programmed to output a pseudo-random step-level signal keyed to its scanning time base. This signal was fed into the MDAS, digitized as one of the 16 analog inputs and recorded in the MDAS output files.

A third IBM-compatible PC was provided with the capability to mount the removable hard drives recorded on by the OLDS and MDAS computers. This computer was used to examine and plot the recorded data in an offline mode. It was also used to continuously log the navigation data from the ship's GPS receiver whenever the ship was underway.

12.1 Control Hardware

The control hardware needed to perform time base synchronization between the OLDS acquired data and the MDAS measured propeller angular orientation consisted of two key elements:

1. a magnetic proximity switch-based shaft encoder mounted on the port propeller shaft to provide a continuous record of its angular position; and
2. the MDAS, consisting of an IBM-compatible personal computer running the Microsoft Windows NT 4.0 operating system and equipped with a 16-channel analog input data acquisition board.

The shaft encoder consisted of two bands of ferromagnetic tabs made from galvanized sheet steel mounted on the port intermediate propeller shaft in the aft motor room. The two bands of steel tabs were mounted on a 5 mm thick layer of sheet rubber. A pair of fast-acting Omron proximity switches were mounted next to the propeller shaft to detect the passage of each band of tabs due to the rotation of the shaft. A square wave was produced by each switch that would transition to the conducting state when a ferromagnetic tab would pass in front of it. In the gaps between the tabs the switch would be in the non-conducting state due to the standoff thickness of the rubber foundation from the propeller shaft surface.

One of the two bands provided a coarse indication of shaft position with alternating tabs and gaps of increasing width starting from the angular position on the shaft of the shaft key, which corresponded to the centre of the spindle axis of blade number 1. The second encoder band provided a fine or vernier position indication using narrower tabs to permit accurate determination of shaft position and speed between the tabs of the coarse band.

The MDAS computer uses a Computerboards DAS 16/330 16-channel analog acquisition board scanning its 16 channels at the same 1000 samples per second per channel as the OLDS data acquisition system.

By recording both of the proximity switch wave trains on the same time base with the pseudo-random time code generated by the OLDS data acquisition time base, the capability was provided to establish the angular position of the port shaft with an accuracy of ±0.2° at any point in time in the corresponding OLDS data record.

12.2 Control Software

The software used to acquire the full-scale data, perform the time base alignment between the OLDS and MDAS data sets, and compute the propeller blade deflections and loads, consisted of four programs:

1. OLDSmaster, the OLDS data acquisition program;
2. OLDSviewer, the program to display time series plots of OLDSmaster data files;
3. MDASmaster, the MDAS data acquisition program; and
4. OLDSloads, the propeller blade load analysis and calculation program.

The OLDSmaster application was written in standard ANSI-C using the Microsoft Visual C/C++ compiler version 6.0. This application is responsible for the OLDS data acquisition and handles all the DSP calls. Once the application is lunched, a binary file is created and filled with the data coming from the three OLDS channels.

The OLDSmaster binary data files can be viewed and analysed with a second program named OLDSviewer. This application is also written in standard ANSI-C but is compiled with a package called CVI/LabWindows, developed by National Instrument.

The MDASmaster data acquisition software was written in standard ANSI-C using the Microsoft Visual C/C++ compiler version 6.0 and the Computerboards data acquisition system Universal Library version 5.02. It was written to control the Computerboards DAS 16/330 analog input board, scanning all 16 analog inputs 1000 times per second and writing the readings as 16-bit binary words containing 12-bit readings per channel to a series of MDAS output data files, each 200 seconds in length. As soon as one file was closed another would be started, either automatically or under operator intervention, whenever the ship was underway in ice and the OLDS data acquisition system was running.

The OLDSloads data analysis and propeller blade loads calculation software was again written in standard ANSI-C using the Microsoft Visual C/C++ compiler version 6.0. It was written to accept as input the series of OLDS propeller blade range data files as well as the corresponding MDAS data files, to read data from both of these and perform time base alignment between them and to produce a combined output data file that included all OLDS and MDAS signals on a common time base. It also provided for displaying time series plots of any of these signals, calculating the blade deflections compensated for the shafting displacements and then applying the load/deflection calibration data to calculate the ice impact loads from the measured blade deflections.

All project software was written to run in the WIN32 environment under Microsoft Windows NT version 4.0.

12.3 Integration of Control Hardware and Software with OLDS

To establish the correlation between the MDAS signals measuring the axial and transverse deflections of the shafting and the angular orientation of the propeller with the OLDS recordings of the range from the bossing instrument housing to the propeller, a number of discrete sets of baseline measurements were made with the installed instrumentation, including:

- measurement of the propeller geometry as a function of propeller angular position under no blade loading, carried out by turning the port propeller slowly on the turning gear while logging data with both the OLDS and MDAS systems; and
- measurement of both OLDS and MDAS signals while running the propellers at various shaft speeds between zero and full power in both ahead and astern modes in ice-free water.

The data from the turning gear tests were then used to establish the undeflected propeller blade geometry for all four blades of the port propeller at specific measured shafting deflections.

The data from the free route tests in ice-free water were used to establish the blade deflections and shafting deflections due to pure hydrodynamic loads on the blades as a function of ship speed and shaft RPM.

The results of these measurements were then stored as tabular data in the OLDSloads program to permit the OLDS range measurements made during propeller-ice interaction to be compensated for the no load blade geometry, and for the shafting deflections and blade deflections due to hydrodynamic loads at icebreaking speeds as a function of shaft speed.

13 Blade/OLDS Calibration

This task addresses the design of the blade load calibration procedure and required fixtures, which results in the construction of a yoke and cable harness that could be fitted to one propeller blade such that a known bending load could be applied to the blade.

13.1 Blade Calibration Test Fixture

The calibration test fixture was designed to permit jacking loads up to 25 tons to be applied to the blades of the Stone Marine propeller at the 0.9 R while measuring the deflections of the blades in the region from 0.7 to 0.85 R.

To do this the propeller was bolted to a cruciform frame fabricated from 36" deep I-beam sections and a pair of hydraulic jacks were arranged in parallel with the hydraulic supply to provide equal loading on two opposite blades at once, thereby avoiding the necessity to react any large bending loads at the propeller hub. Instead, the jacking loads were reacted as bending in the deep I-beams and as tension in four large diameter bolts passing axially through the propeller hub and securing it to the I-beam frame.

To measure the deflections of the blades relative to the hub of the propeller, a rigid space frame was constructed and mounted across the aft end of the hub to carry a series of precision linear variable differential transformers (LVDTs) capable of measuring the deflections with a resolution of 4 μm. The load being applied to the blade was measured with a calibrated strain gauge load cell placed in series with one of the two hydraulic jacks. Although jacking loads were applied to two opposite blades at once, measurements were made on only one of these two blades at a time, then the load cell with LVDT array was moved to the opposite blade and it was calibrated. The propeller was then unbolted from the frame, rotated through 90 degrees and re-secured, and the remaining two blades were calibrated in the same fashion.

The newly cast port propeller for the CCGS *Louis S. St. Laurent* is shown in Figure 24 mounted to the calibration fixture. The load cell in series with the hydraulic jack can be seen in the left of the picture and the four LVDT displacement sensors can be seen mounted to the space frame above the blade.

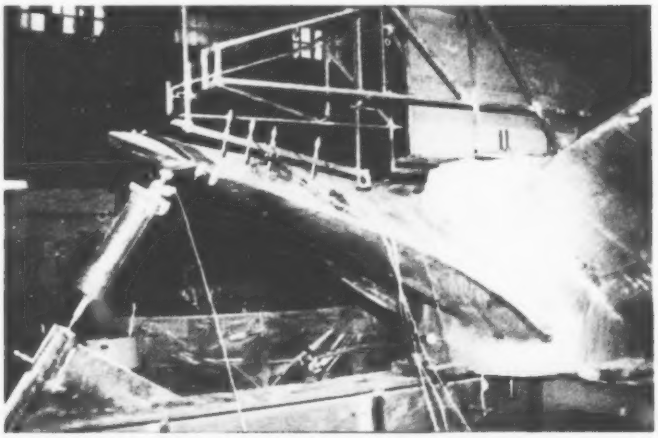


Figure 24: New port propeller on load versus blade deflection calibration frame

13.2 Blade Calibration Results

Each blade was identified as it was calibrated according to the manufacturer's convention of numbering them 1 through 4 with blade number 1 being the one over the keyway in the hub that keys it to the propeller shaft.

The hydraulic load was applied with a hand Enerpac pump in increments of 5 tons while recording the output of the load cell and the LVDTs on a common time base using a multi-channel A/D converter interface in a standard PC. Each signal was recorded 20 times per second during the loading and unloading phase with the readings being plotted to the screen and logged to a disk file simultaneously.

For each blade a number of calibration runs were made moving the LVDT array both in the radial and chordwise directions of the blade. For all runs, however, the load was applied at 0.9 R on the blade spindle axis and at the same angle at which the loading geometry was fixed.

It was determined that the load-deflection curve for all blades and all load cases was linear to within better than 0.5 percent of the full-scale range for all loading cases and no detectable hysteresis was observed, showing that the loading frame and bolting arrangement provided sufficient stiffness.

The average stiffness of the four blades corresponded to 1.0 mm of deflection at 0.8 R for each 10 tons of load acting normal to the blade suction side at 0.9 R on the spindle axis.

14 Underwater Instrumentation Packaging

This task addresses the detailed design of the ice-strengthened underwater mounting and instrument packaging system, including welding and strength calculations for the lead candidate vessel. To provide for maximum portability among ships, the underwater housing should be designed as two elements: the first one consisting of a watertight enclosure for the underwater instrumentation and the second composed of an ice-strengthened adapter allowing for a snug fit of the watertight housing to the ship bossing.

14.1 Watertight Housing Design

The emission and collection optics as well as the underwater subsystem electronics are located in an watertight housing inserted into a supporting shoe welded to the hull of the ship. The precise location and orientation of the optical sub-assemblies inside the housing are dictated by the location and orientation of the housing itself and by the selected laser trajectories on the blades' surfaces. The front side of the housing has seven windows, three for each of the collection and emission optics channels, while the last one is used for the video camera.

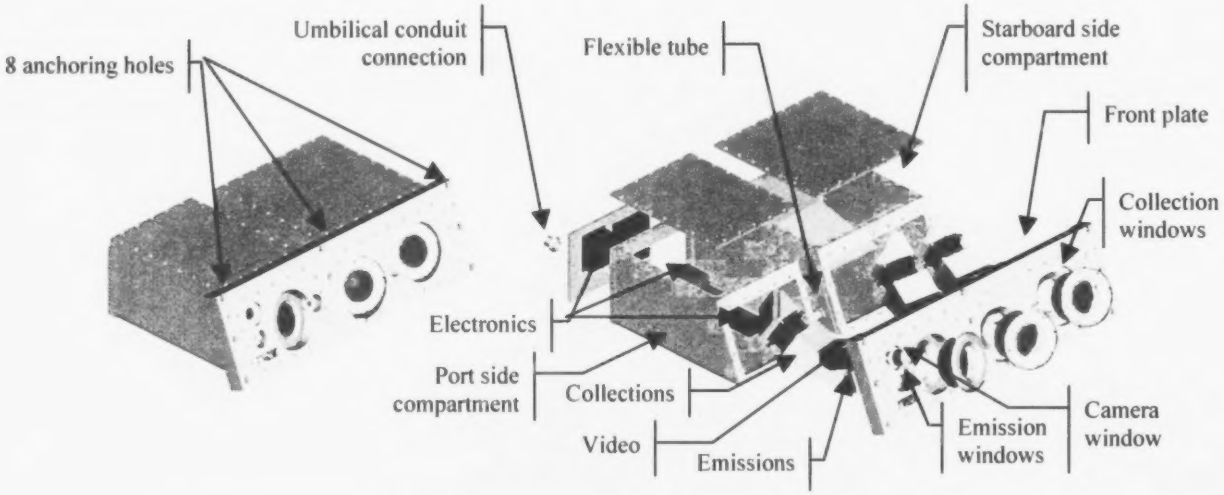
The main purpose of the watertight housing is to protect all optical systems and electronics that are placed underwater. Since susceptibility to corrosion was a concern, stainless steel was chosen for all housing parts and bolts. Protection is not only against water but also against ice blocks. The watertight housing design had also to ensure:

- compatibility with the ice-strengthened shoe;
- elevation of approximately 25 degrees for the optical axis;
- great positioning stability between each emission and collection; and
- sufficient space for three emission and collection optics assemblies, video camera and underwater subsystem electronics.

To achieve this, a dual-compartment housing was designed as shown in Figure 25. The geometry was driven by the presence of the centre stiffener of the ice-strengthened shoe. Wires and optical fibres were fed from one compartment to another through a flexible tube connecting the two compartments. One emission and two collection optics assemblies were placed in the starboard side compartment while one collection and two emission optics assemblies, along with the video camera and most of the electronics, were placed in the port side compartment.

Because of machining considerations and also to provide access to all components, a minimum number of openings had to be included. Other than the windows, there is a total of five openings in the housing. O-ring seals were used to provide proper leakage protection and ease of opening and closing in the field.

To ensure the stability of the optical alignment within each pair of emission and collection optics assemblies, a single plate was used to connect the two compartments and to support all the optical assemblies. The front plate was also used to anchor the hole housing to the ice-strengthened shoe and it was the only part of the housing exposed to ice impact. A 2" thick stainless steel plate was used. That thickness was also sufficient to place the windows.


Umbilical conduit connection
8 anchoring holes
Flexible tube
Starboard side compartment
Front plate
Collection windows
Electronics
Port side compartment
Collections
Video
Emissions
Emission windows
Camera window

Assembled view **Exploded view**

Figure 25: Watertight housing assembly

Each window is made of Lexan, which has good optical properties and excellent mechanical properties. A conical shape (as developed by Piccard) combined to O-ring seals enabled excellent protection from ice and leakage from 0 to at least 7 psi (the water pressure at a 15 ft. depth) of external water pressure. Collection optics windows are 3/4" thick while others are 5/16" thick.

Since water temperature is around 0°C, condensation on the inner walls of the housing and interior face of the windows is possible. To protect the electronics and to maximize light transmission through the windows, continuous dry-air circulation was necessary as described in section 7.4.3. This approach forced rapid evaporation of any water and also offered protection against small leaks that could occur.

Since water infiltration in the housing meant complete failure of the project, tightness was tested with a helium leak-detection system prior to shipping. The performance of the housing was more than sufficient. The result is a very rugged housing weighing approximately 350 lb.

14.2 Watertight Housing Manufacturing

The watertight housing is made of three sub-assemblies as described in section 14.1. Those are the port and starboard side compartments and the front plate that holds the windows and the two compartments together.

Whenever possible, folded or soldered parts were used to minimize any chance of water infiltration. For the openings, O-ring type joints were used for their simplicity of installation in the field. Like any removable tight joints, good surface roughness and flatness of the two mating parts is the key to success.

For the front plate, a thickness of 2" was necessary to support and protect the windows. It also ensured excellent rigidity between the two compartments and provided excellent anchoring in the ice-strengthened shoe.

The main challenge was the machining of the seven window openings in the front plate. These are of conical shape, as described in section 14.1, and different pair of angles determines each axis. The material type combined to the geometry of the openings and the weight of the plate forced the use of very slow cutting speeds on a CNC machine. Also, a lapping process had to be used to obtain the proper surface roughness. The total machining time for this plate alone was around 100 hours.

14.3 Ice Strengthening Conceptual Design

The objective of this task was to provide a method of attaching the OLDS underwater optics package to the bossing of the ship while protecting it from damage by impacts with large ice pieces. To minimize the weight of the OLDS underwater package itself, it was decided that only one face of this package, the one carrying the optical windows, should be designed as an ice-strengthened component.

To protect the rest of the OLDS package from ice damage and to provide attachment support to the hull, an ice-strengthened shoe was designed and its detailing, fabrication and installation were coordinated with the shipyard where the CCGS *Louis S. St. Laurent* was dry-docked in March and April of 1999 for fitting of the new Stone Marine propellers.

This shoe was required to provide rigid attachment of the OLDS housing to the top of the port bossing, at the correct distance from the propeller and with the correct orientation for the optics to be trained on the right portions of the propeller disk. It had to provide sufficient strength to protect itself and the optical package within it from damage by the largest multi-year ice pieces that could potentially come in contact with it. It also had to accommodate the installation and removal of the OLDS underwater package by divers while at sea.

The philosophy adopted for the ice strengthening of this shoe was to ensure that it was fabricated to be at least as strong as the hull itself where it was attached. This was accomplished by designing an enclosure around three heavy longitudinal stiffeners made from 1-5/8" steel plate attached by double penetration welds to the 1-5/8" bossing plate. The centre stiffener divides the housing into two chambers and was offset toward the outboard side of the structure to make the inboard chamber large enough to accommodate two of the three sets of optics while the outboard side would house the third one.

The forward end, top and sides of the shoe were faired in with 1" plate. The aft ends of the three stiffeners were cut at an angle of 23° to the normal to the port shaft line to form three bolting surfaces to which the ice-strengthened face of the OLDS package could be bolted.

As the owners did not wish to make a through-hull penetration for the optical cable to the underwater package it was decided to fair an ice-strengthened cable conduit to the outside of the hull from the bossing, up the side of the ship to the level of the main deck. This conduit was fabricated by welding two courses of 1.5 in.^{2} bar to the hull 2" apart and then fairing these and plating over them with 1" flat plate. This left a rectangular cable passage between the two square bars 1.5" deep by 2" in width, which was judged sufficient to accommodate an optical cable assembly up to 1" in diameter. Because of the requirement to easily pull such a large cable through the conduit, it was laid out on the side of the hull with very long radius bends where it transitioned from the bossing onto the hull proper and where it changed direction from horizontal to vertical on the side of the hull. The specification called for a minimum radius of curvature at all bends of not less than 6 ft.

Figure 26 and Figure 27 show the ice-strengthened shoe as it was fabricated to the port bossing. In Figure 27 the shoe is shown with its aft opening closed by a temporary blanking plate to be removed in the Arctic when the OLDS instrument is installed by divers. A total of eight ½" cap screws are used to secure either the blanking plate or the OLDS instrument into the shoe and these are required to be wire-locked to prevent them working loose over time because of vibration exposure.

Figure 26: Ice-strengthened shoe on top of port bossing before painting

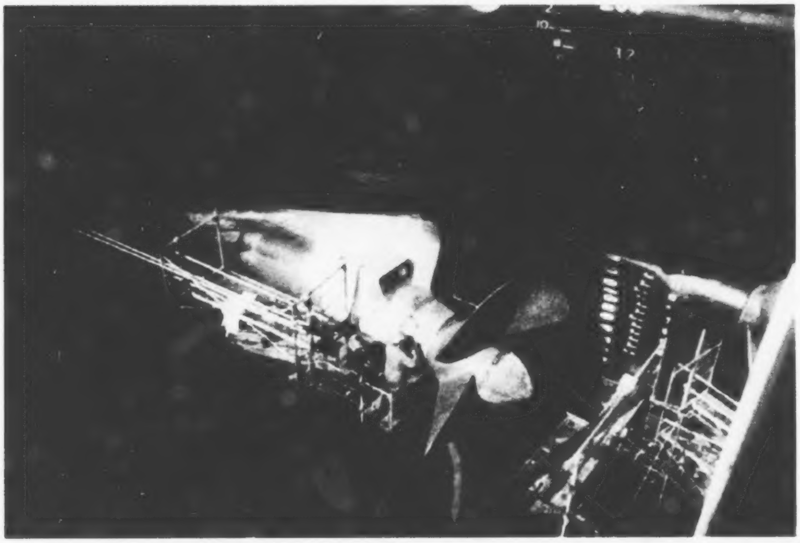


Figure 27: Ice-strengthened shoe on bossing and port propeller

Figure 28 shows the ice-strengthened optical cable conduit up the side of the ship after it was fabricated in the dry-dock.

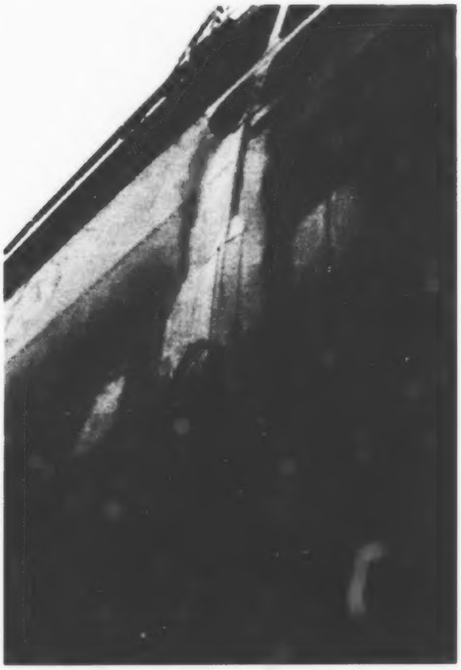


Figure 28: Ice-strengthened fairing for cable conduit up the outside of the hull

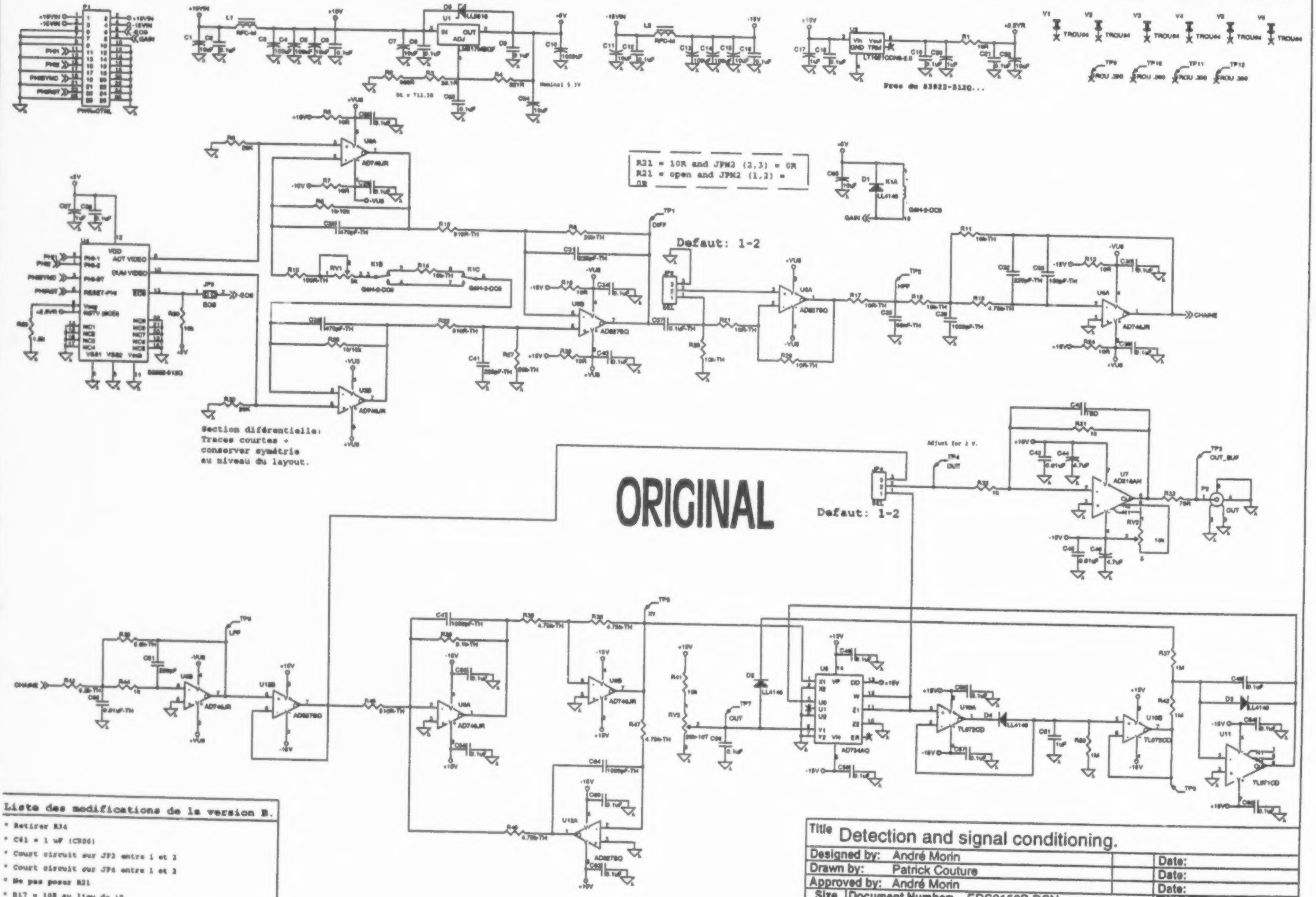
15 Conclusion

This report presents the design of a system that performs ice load measurements. This system is based on conventional triangulation and uses three laser range finders aimed at the propeller blades to monitor deformations in real time. As the propeller rotates, each laser range finder describes an arc of a circle on the blades. Using template-matching techniques, the range values for these series of arcs can be used to infer the actual ice-induced blade deformations.

The system provides range measurements at a rate of 1 kHz on three different channels and is accurate within 0.5 mm at distances in excess of 3 m. It was designed so that it can be installed by divers just prior to the conduct of ice trials.

Early in 1999 it was identified that the most suitable candidate vessel for the initial use of the system would be the Canadian Coast Guard's heavy icebreaker CCGS *Louis S. St. Laurent*. The ship was dry-docked in the spring of 1999, affording an opportunity to fit the ice-strengthened fixture. The ship was then deployed to the Canadian Arctic for ice trials.

APPENDIX A
Electronic Drawings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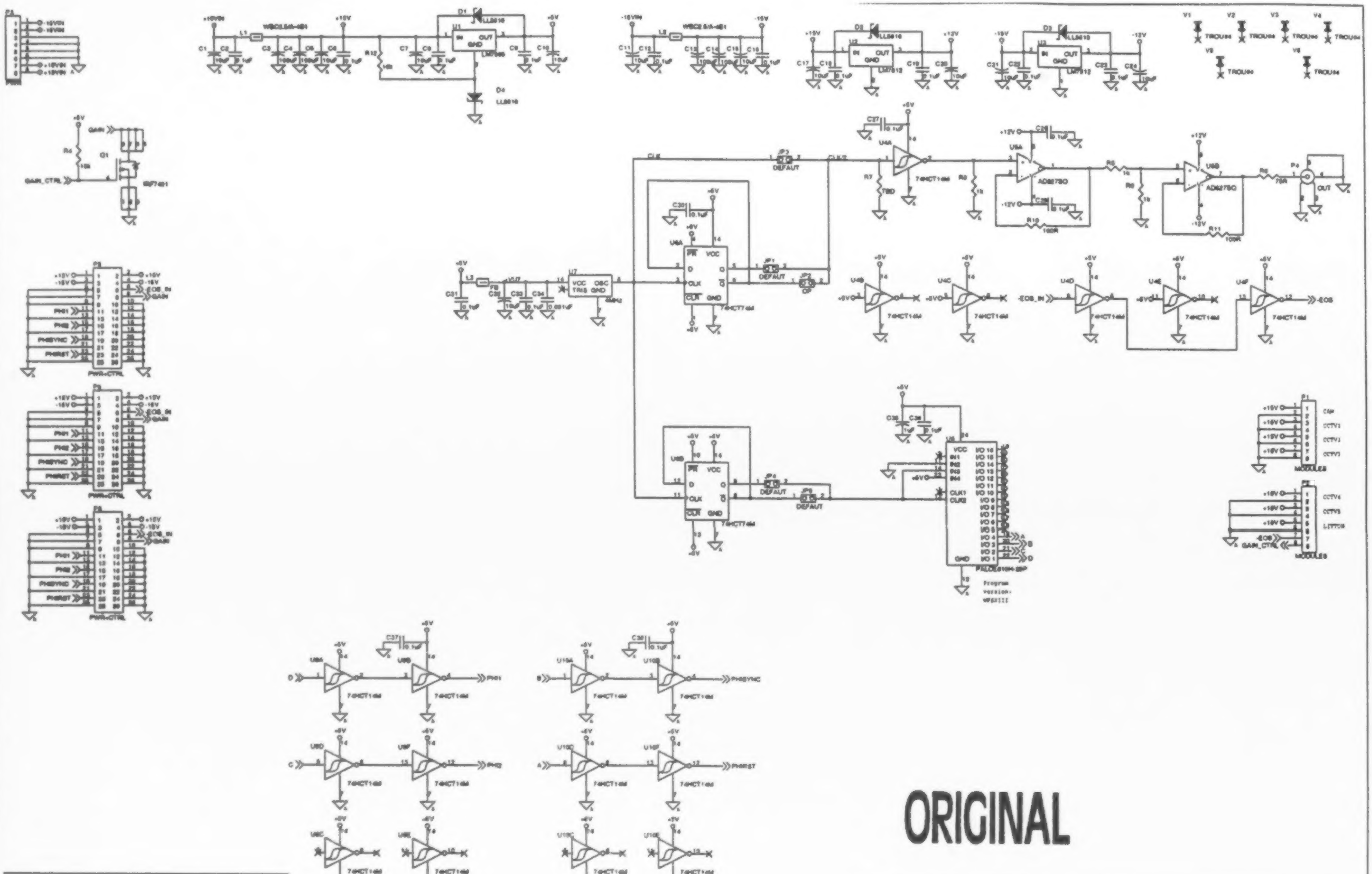
R21 = open and JPM2 (1,2) =
0R
Defaut: 1-2
Section différentielle:
Traces courtes -
conserver symétrie
au niveau du layout.
Defaut: 1-2
Adjust for 3 V.
Pres de 83822-3120...
Nominal 5.3V
CHAINE
OUT_BUF
OUT
DIFF
HPF
LPF
GAIN
EOS
AD746JR
AD827BQ
AD734AQ
AD818AN
TL072CD
TL071CD
LL4148
TROU
ORIGINAL

Liste des modifications de la version B.

- Retirer R34
- C61 = 1 uF (CR06)
- Court circuit sur JP3 entre 1 et 3
- Court circuit sur JP6 entre 1 et 3
- Ne pas poser R21
- R17 = 10R au lieu de 1R.
- C35 = 68nF au lieu de 680nF.

Title Detection and signal conditioning.
Designed by: André Morin
Drawn by: Patrick Couture
Approved by: André Morin
Date:
Date:
Date:
Size A
Document Number: EDS0150B.DSN
Project number: 7737
INO
Rev B
Date: Tuesday, October 05, 1999
Sheet 1 of 1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-15VIN
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L1
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D1
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U1
IN
OUT
GND
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LL5818
-15VIN
L2
-15V
D2
U2
LM7812
+12V
D3
U3
-12V
V1
V2
V3
V4
V5
V6
TROU04
R4
10k
Q1
GAIN
GAIN_CTRL
IRF7401
P5
P6
P7
PHI1
PHI2
PHISYNC
PHIRST
-EOS_IN
PWR-CTRL
CLK
JP3
DEFAUT
CLK/2
C27
0.1uF
U4A
R7
TBD
74HCT14M
U5A
AD8270
R5
R9
1k
R10
100R
U5B
R11
R6
75R
P4
OUT
U6A
PR
VCC
D
Q
CLK
CLR
GND
74HCT74M
JP1
JP2
OP
U7
VCC
OSC
TRIS
GND
U4B
U4C
U4D
U4E
U4F
-EOS
U6B
JP4
JP5
U8
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CLK2
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version:
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U9B
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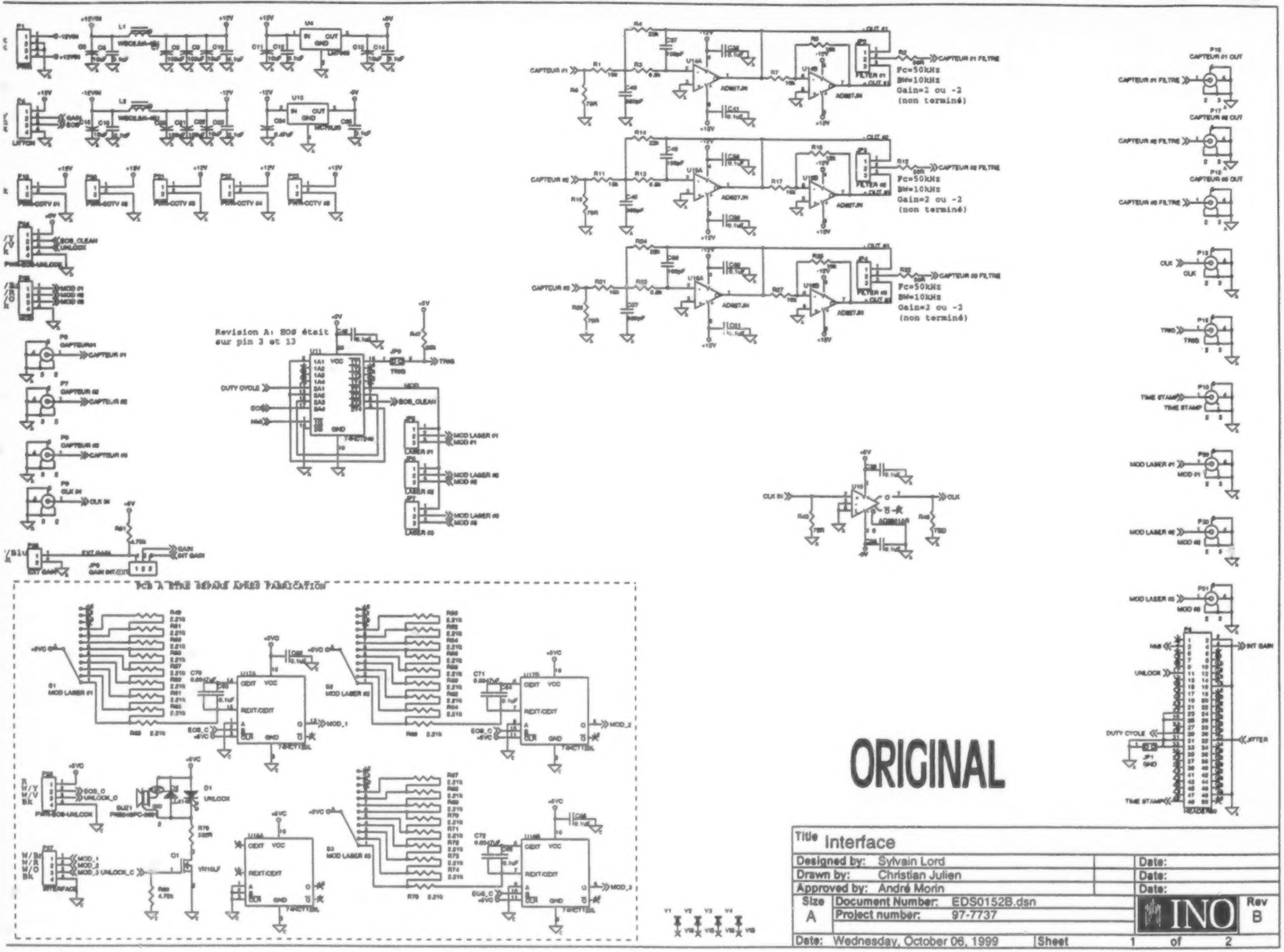
U9D
U9E
U9F
U10A
U10B
U10C
U10D
U10E
U10F
C37
C38
A
B
C
D

iste des modifications de la version B.

Ajout de R12 (10k) entre 1 et 2 de U1
Ajout de D4 (LL5818) entre pin 2 de U1 et GND A
Pin 6 de P5,P6 et P7 à pin 9 de U6D
Pin 8 de U6D à pin 13 de U4F et pin 12 à -EOS de P2
Ajout de U10 et C38 pour buffer PHIRST et PHISYNC
Ajout de U9 et C37 pour buffer PHI1 et PHI2
R9=1k

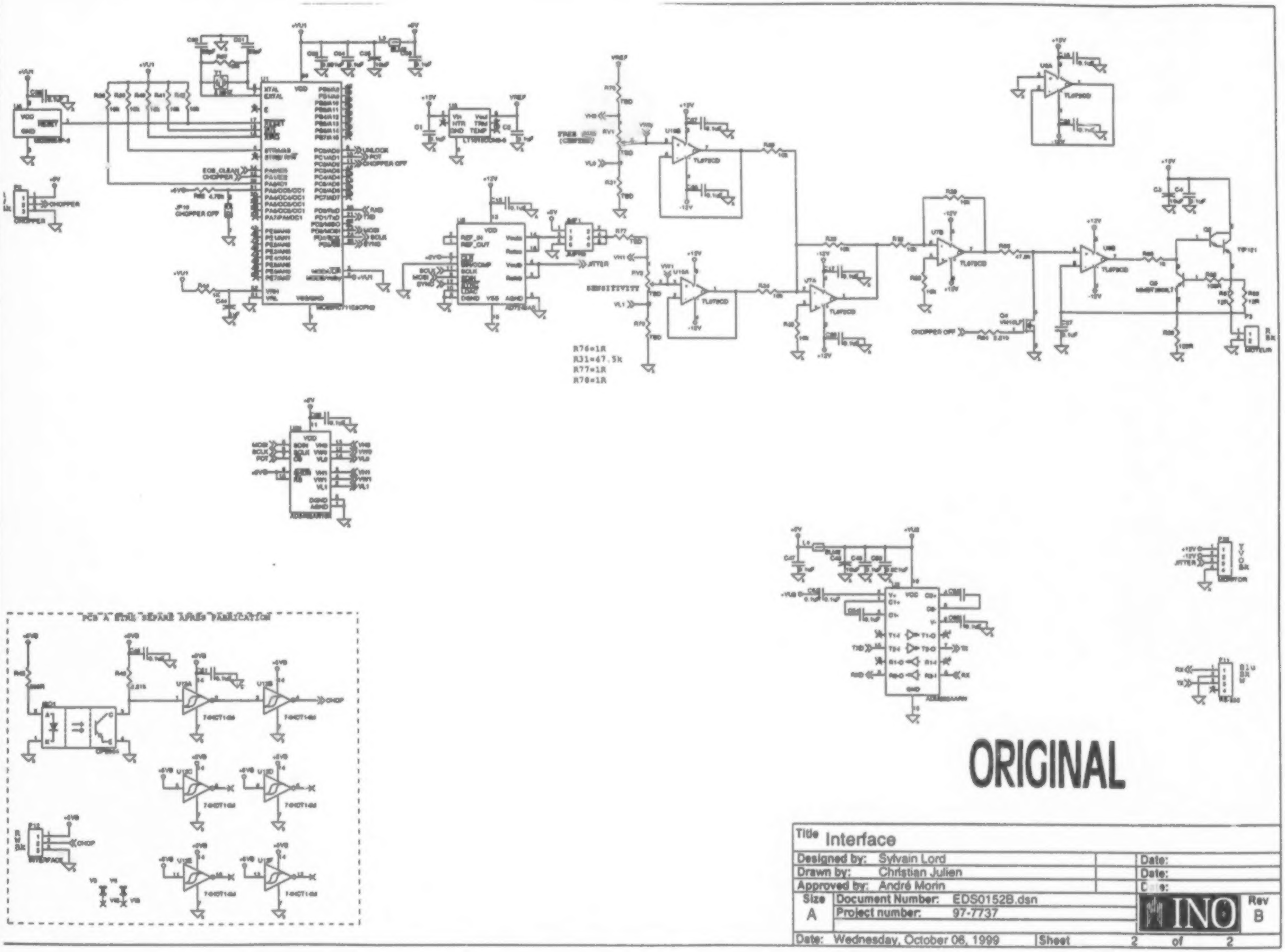
ORIGINAL

Title U.W. subunit controller.		
Designed by: Yvan Mimeault		Date:
Drawn by: Patrick Couture		Date:
Approved by: André Morin		Date:
Size A	Document Number: EDS0151B.DSN Project number: 7737	INO Rev B
Date: Wednesday, October 06, 1999	Sheet 1 of 1	


CAPTEUR #1 FILTRE
CAPTEUR #2 FILTRE
CAPTEUR #3 FILTRE
Fc=50kHz
BW=10kHz
Gain=2 ou -2
(non terminé)
AD827JN
CAPTEUR #1
CAPTEUR #2
CAPTEUR #3
CLK IN
CLK
TRIG
TIME STAMP
MOD LASER #1
MOD LASER #2
MOD LASER #3
Revision A: EOS était
sur pin 3 et 13
DUTY CYCLE
EOS_CLEAN
UNLOCK
INT GAIN
JITTER
PCB À ÊTRE SÉPARÉ APRÈS FABRICATION
MOD_1
MOD_2
MOD_3
HEADER50

ORIGINAL

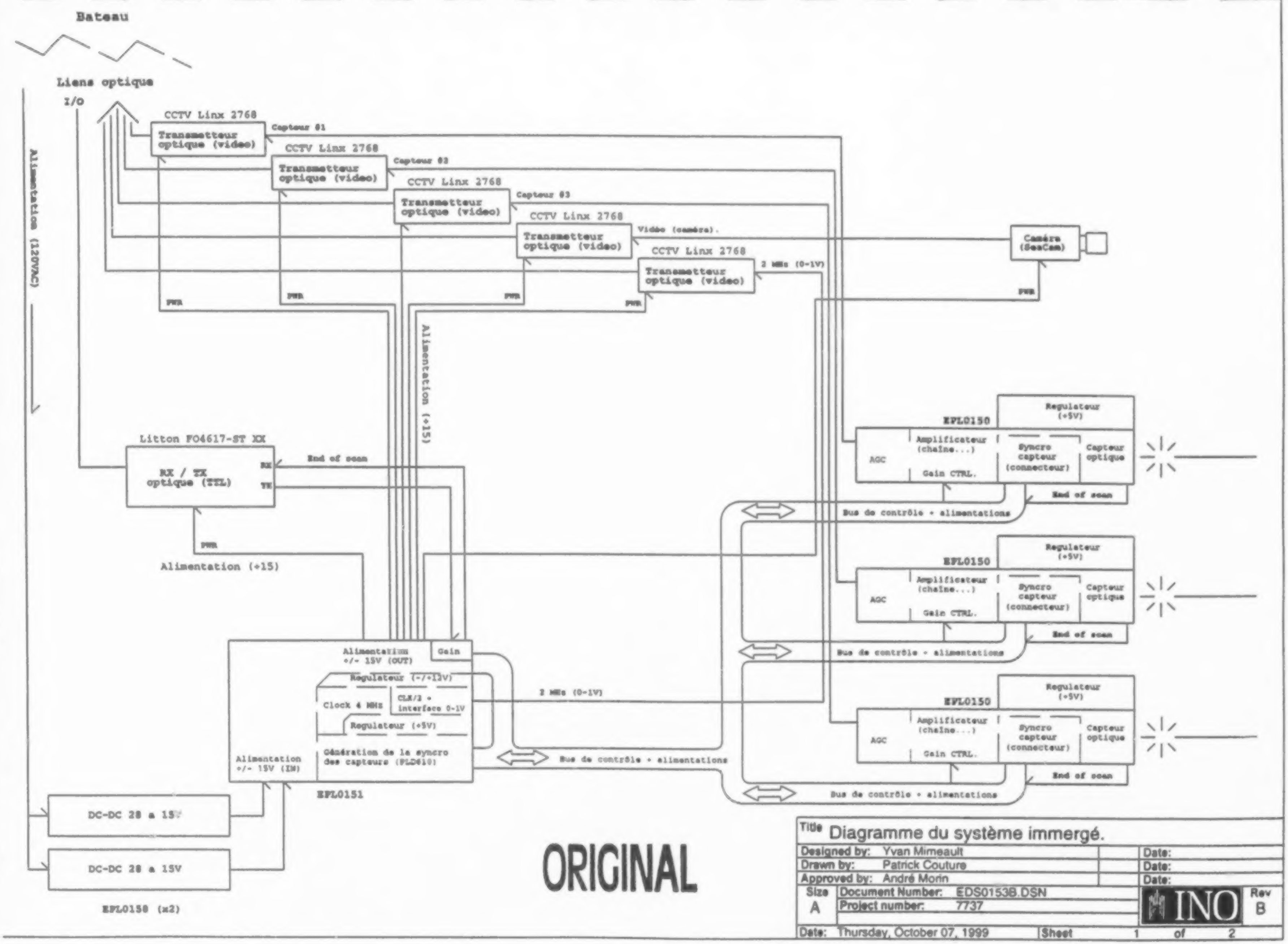
Title Interface		
Designed by: Sylvain Lord		Date:
Drawn by: Christian Julien		Date:
Approved by: André Morin		Date:
Size A	Document Number: EDS0152B.dsn Project number: 97-7737	INO Rev B
Date: Wednesday, October 06, 1999	Sheet 1 of 2	



R76=1R
R31=47.5k
R77=1R
R78=1R
CHOPPER
CHOPPER OFF
JITTER
SENSITIVITY
TL072CD
TIP101
MOTEUR
MONITOR
RS232
INTERFACE
PCB A ETRE SEPARE APRES FABRICATION

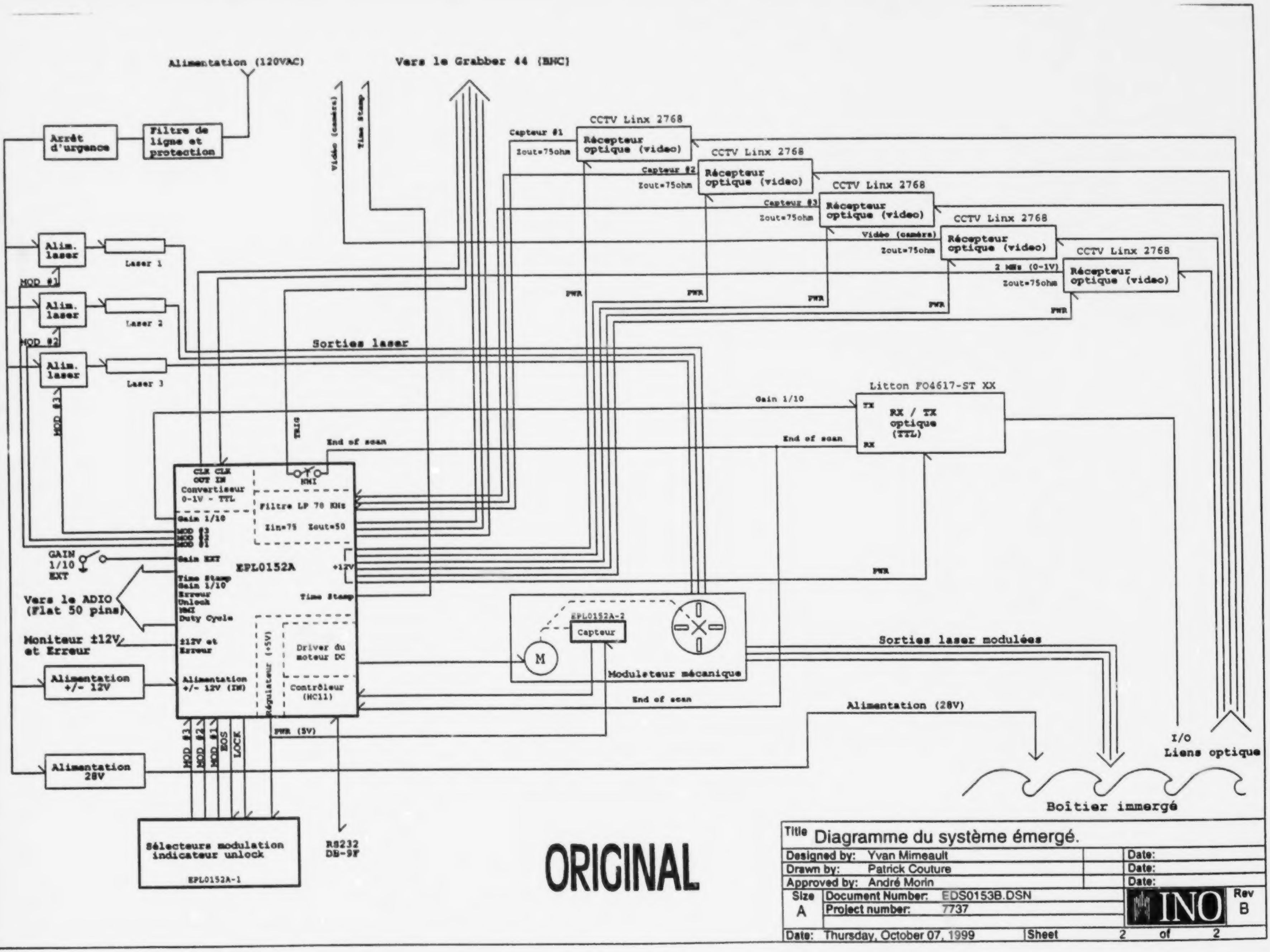
ORIGINAL

Title Interface			
Designed by: Sylvain Lord		Date:	
Drawn by: Christian Julien		Date:	
Approved by: André Morin		Date:	
Size A	Document Number: EDS0152B.dsn Project number: 97-7737	INO	Rev B
Date: Wednesday, October 06, 1999	Sheet	2 of 2	


Bateau
Liens optique
I/O
Alimentation (120VAC)
CCTV Linx 2768
Transmetteur optique (video)
Capteur 01
CCTV Linx 2768
Transmetteur optique (video)
Capteur 02
CCTV Linx 2768
Transmetteur optique (video)
Capteur 03
CCTV Linx 2768
Transmetteur optique (video)
Vidéo (caméra).
CCTV Linx 2768
Transmetteur optique (video)
2 MHz (0-1V)
Caméra (SeaCam)
PWR
PWR
PWR
PWR
PWR
PWR
Alimentation (+15)
Litton FO4617-ST XX
RX / TX optique (TTL)
RX
TX
End of scan
PWR
Alimentation (+15)
Alimentation +/- 15V (OUT)
Gain
Regulateur (-/+12V)
Clock 4 MHz
CLK/2 + interface 0-1V
Regulateur (+5V)
Génération de la syncro des capteurs (PLD610)
Alimentation +/- 15V (IN)
EPL0151
2 MHz (0-1V)
Bus de contrôle + alimentations
DC-DC 28 a 15V
DC-DC 28 a 15V
EPL0158 (x2)
EPL0150
Regulateur (+5V)
AGC
Amplificateur (chaîne...)
Gain CTRL.
Syncro capteur (connecteur)
Capteur optique
End of scan
Bus de contrôle + alimentations
EPL0150
Regulateur (+5V)
AGC
Amplificateur (chaîne...)
Gain CTRL.
Syncro capteur (connecteur)
Capteur optique
End of scan
Bus de contrôle + alimentations
EPL0150
Regulateur (+5V)
AGC
Amplificateur (chaîne...)
Gain CTRL.
Syncro capteur (connecteur)
Capteur optique
End of scan
Bus de contrôle + alimentations

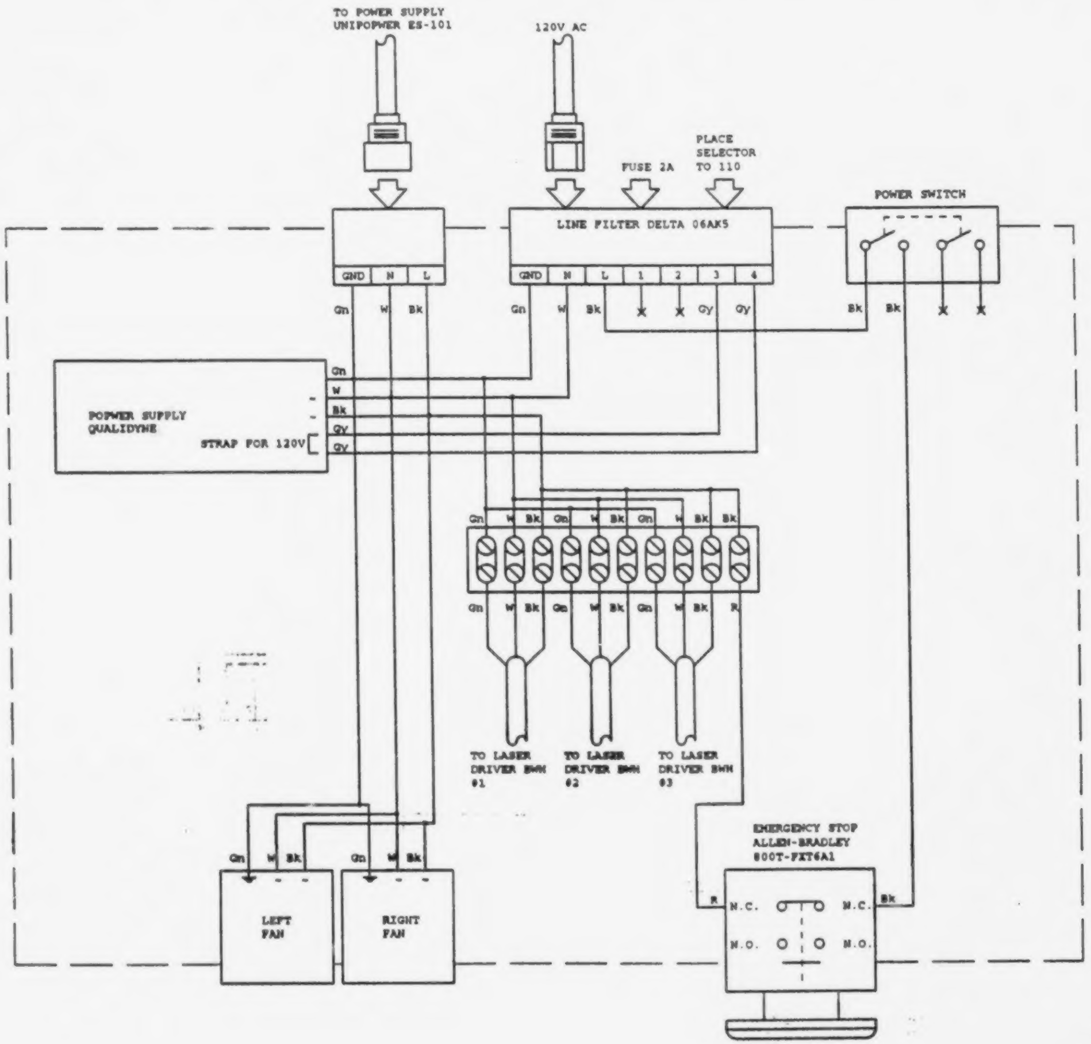
ORIGINAL

Title Diagramme du système immergé.
Designed by: Yvan Mimeault Date:
Drawn by: Patrick Couture Date:
Approved by: André Morin Date:
Size A Document Number: EDS0153B.DSN
Project number: 7737
INO Rev B
Date: Thursday, October 07, 1999 Sheet 1 of 2


Alimentation (120VAC)
Vers le Grabber 44 (BNC)
Arrêt d'urgence
Filtre de ligne et protection
Vidéo (caméra)
Time Stamp
Capteur #1
Zout=75ohm
CCTV Linx 2768
Récepteur optique (video)
Capteur #2
Capteur #3
Vidéo (caméra)
2 MHz (0-1V)
PWR
Alim. laser
Laser 1
Laser 2
Laser 3
MOD #1
MOD #2
MOD #3
Sorties laser
Litton FO4617-ST XX
RX / TX optique (TTL)
TX
RX
Gain 1/10
End of scan
TRIG
NMI
CLK OUT
CLK IN
Convertisseur 0-1V - TTL
Filtre LP 70 KHz
Zin=75 Zout=50
Gain 1/10
MOD #3
MOD #2
MOD #1
Gain EXT
EPL0152A
+12V
Time Stamp
Gain 1/10
Erreur
Unlock
NMI
Duty Cycle
±12V et Erreur
Alimentation +/- 12V (IN)
Régulateur (+5V)
Driver du moteur DC
Contrôleur (HC11)
GAIN 1/10 EXT
Vers le ADIO (Flat 50 pins)
Moniteur ±12V et Erreur
Alimentation +/- 12V
Alimentation 28V
EPL0152A-2
Capteur
M
Moduleteur mécanique
Sorties laser modulées
End of scan
Alimentation (28V)
I/O
Liens optique
Boitier immergé
PWR (5V)
MOD #3
MOD #2
MOD #1
EOS
LOCK
Sélecteurs modulation indicateur unlock
EPL0152A-1
RS232
DB-9F

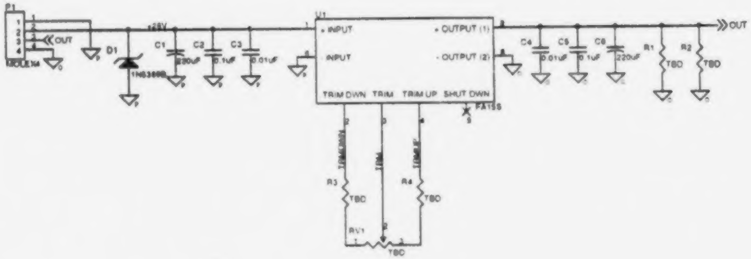
ORIGINAL

Title Diagramme du système émergé.				
Designed by: Yvan Mimeault			Date:	
Drawn by: Patrick Couture			Date:	
Approved by: André Morin			Date:	
Size A	Document Number: EDS0153B.DSN Project number: 7737		INO	Rev B
Date: Thursday, October 07, 1999	Sheet	2	of	2


TO POWER SUPPLY
UNIPOPWER ES-101
120V AC
FUSE 2A
PLACE SELECTOR TO 110
LINE FILTER DELTA 06AK5
POWER SWITCH
GND
N
L
1
2
3
4
Gn
W
Bk
Gy
POPWER SUPPLY
QUALIDYNE
STRAP FOR 120V
R
TO LASER DRIVER BWH #1
TO LASER DRIVER BWH #2
TO LASER DRIVER BWH #3
EMERGENCY STOP
ALLEN-BRADLEY
800T-FXT6A1
N.C.
N.O.
LEFT FAN
RIGHT FAN

ORIGINAL

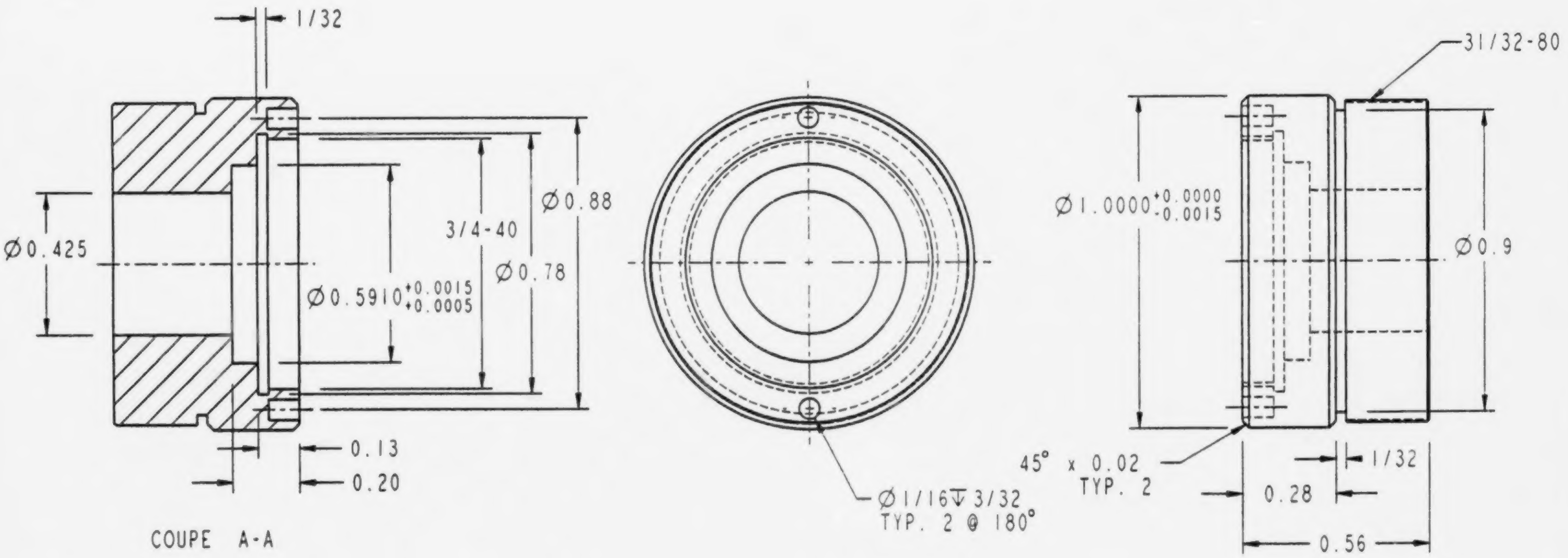
Title Câblage AC système émergé			
Designed by: Sylvain Lord		Date:	
Drawn by: Christian Julien		Date:	
Approved by: André Morin		Date:	
Size A	Document Number: ECA0011A.dsn Project number: 97-7737	INO	Rev A
Date: Thursday, October 07, 1999	Sheet 1 of 1		


P1
1
2
3
4
OUT
MOLEX4
D1
1N5369B
+28V
C1
220uF
C2
0.1uF
C3
0.01uF
U1
+ INPUT
- INPUT
+ OUTPUT (1)
- OUTPUT (2)
TRIM DWN
TRIM
TRIM UP
SHUT DWN
PA15S
C4
0.01uF
C5
0.1uF
C6
220uF
R1
TBD
R2
TBD
OUT
TRIMDOWN
TRIM
TRIMUP
R3
TBD
R4
TBD
RV1
TBD

COPIE

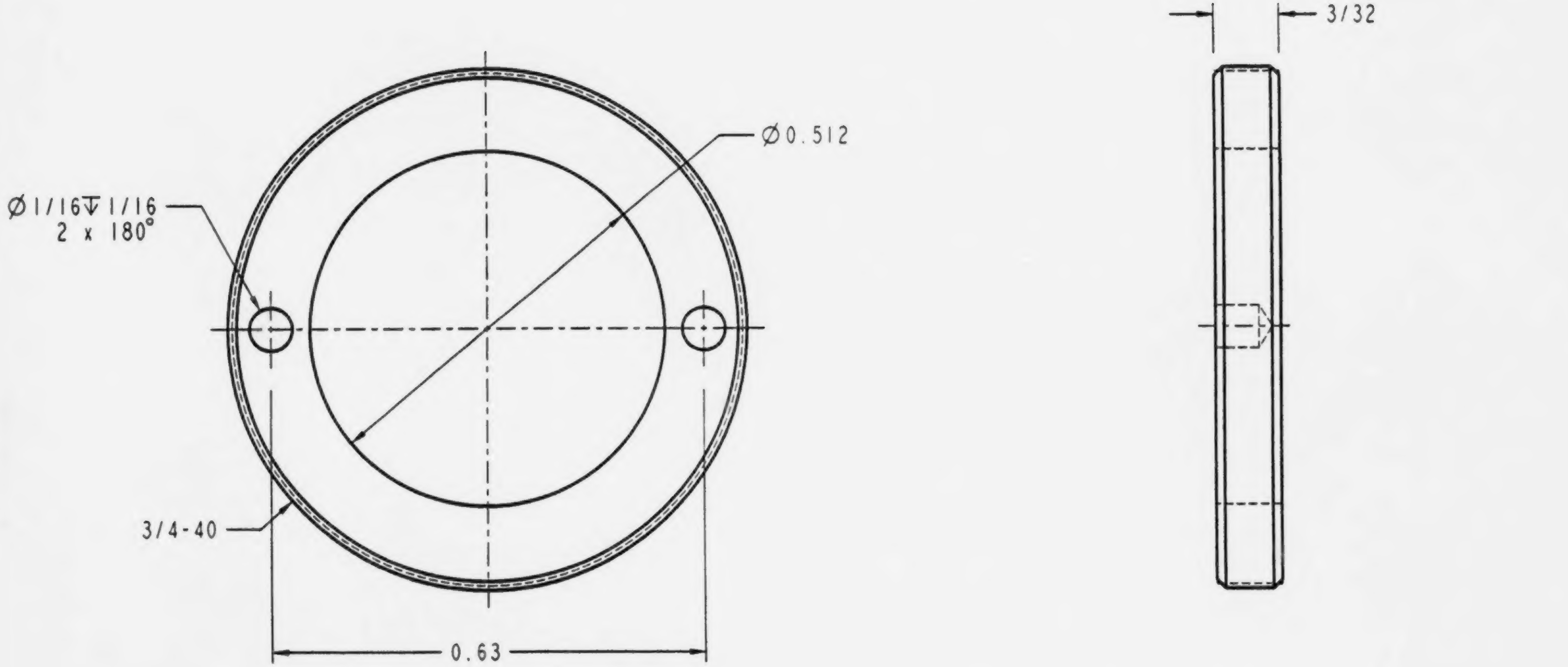
Title U.W. Subunit			
Designed by: Patrick Couture		Date:	
Drawn by: Patrick Couture		Date:	
Approved by: André Morin		Date:	
Size A	Document Number: EDS0158A Project number: 7737	INO	Rev A
Date: Thursday, October 07, 1999	Sheet	1 of 1	

APPENDIX B
Mechanical Drawings


1/32
Ø0.425
Ø0.5910 +0.0015 +0.0005
3/4-40
Ø0.88
Ø0.78
0.13
0.20
COUPE A-A
Ø1/16↧3/32
TYP. 2 @ 180°
31/32-80
Ø1.0000 +0.0000 -0.0015
Ø0.9
45° x 0.02
TYP. 2
1/32
0.28
0.56

ORIGINAL

TOLÉRANCES x/x ± 1/32" .x ± .010" .xx ± .005" .xxx ± .002" Angle à 90° ± 1/2° Fini de surface 63√	INO NOI		369, rue Franquet Sainte-Foy, Québec Canada G1P 4N8 TÉL. : (418) 657-7006 FAX : (418) 657-7009		
	Cellule #1				
	CONÇU : N. Desnoyers	DESSINÉ : L. Simard	APPROUVÉ : A. Morin		
	QUANTITÉ : 1	ÉCHELLE : 2:1	DATE : 07/23	FEUILLE de	VÉRIFIÉ :
	MATÉRIEL : Aluminium anodise noir	9707	7737	00001	FORMAT A



ORIGINAL

TOLÉRANCES

x/x	± 1/32"
.x	± .010"
.xx	± .005"
.xxx	± .002"
Angle à 90°	± 1/2°
Fini de surface	63√

INO NOI

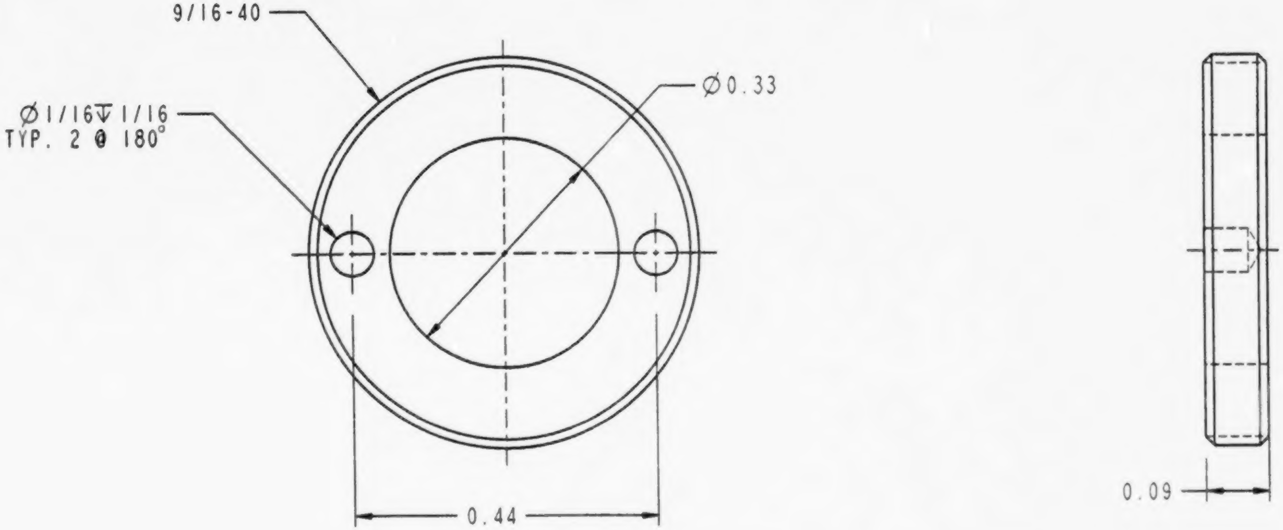
369, rue Franquet
Sainte-Foy, Québec
Canada G1P 4N8
TÉL. : (418) 657-7006
FAX : (418) 657-7009

Bague #1

CONÇU : N. Desnoyers	DESSINÉ : L. Simard	APPROUVÉ : A. Morin

QUANTITÉ : 1	ÉCHELLE : 4:1	DATE : 07/23	FEUILLE de	VÉRIFIÉ :

MATÉRIEL : Aluminium anodisé noir	9707	7737	00002	FORMAT A



ORIGINAL

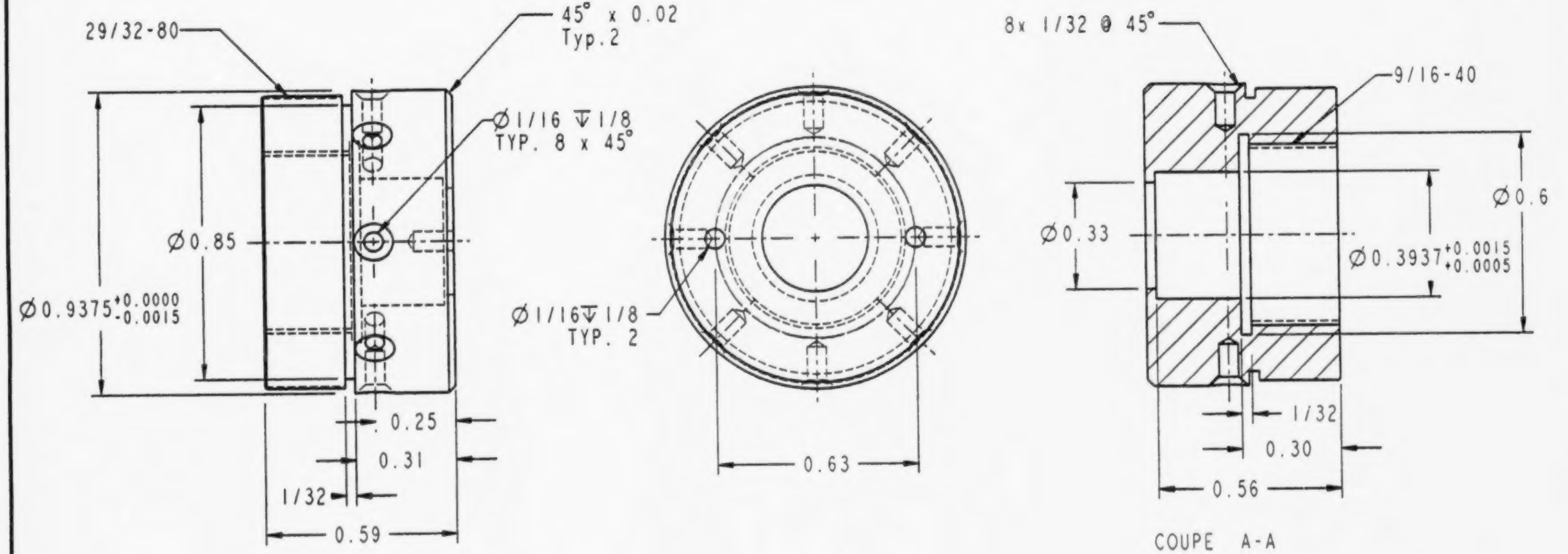
TOLÉRANCES
x/x ± 1/32"
.x ± .010"
.xx ± .005"
.xxx ± .002"
Angle à 90° ± 1/2°
Fini de surface $\sqrt[63]{}$

INO NOI

369, rue Franquet
Sainte-Foy, Québec
Canada G1P 4N8
TÉL. : (418) 657-7006
FAX : (418) 657-7009

Bagne #2

CONÇU : N. Desnoyers
DESSINÉ : L. Simard
APPROUVÉ : A. Morin
QUANTITÉ : 1
ÉCHELLE : 4:1
DATE : 01/23
FEUILLE de
VÉRIFIÉ :
MATÉRIEL Aluminium anodise noir
9707
7737
00003
FORMAT A


29/32-80
45° x 0.02
Typ.2
Ø1/16 ⩡ 1/8
TYP. 8 x 45°
Ø0.85
Ø0.9375 +0.0000 -0.0015
0.25
0.31
1/32
0.59
Ø1/16 ⩡ 1/8
TYP. 2
0.63
8x 1/32 @ 45°
9/16-40
Ø0.33
Ø0.6
Ø0.3937 +0.0015 +0.0005
1/32
0.30
0.56
COUPE A-A

ORIGINAL

TOLÉRANCES

x/x	± 1/32"
.x	± .010"
.xx	± .005"
.xxx	± .002"
Angle à 90°	± 1/2°
Fini de surface	63√

INO NOI

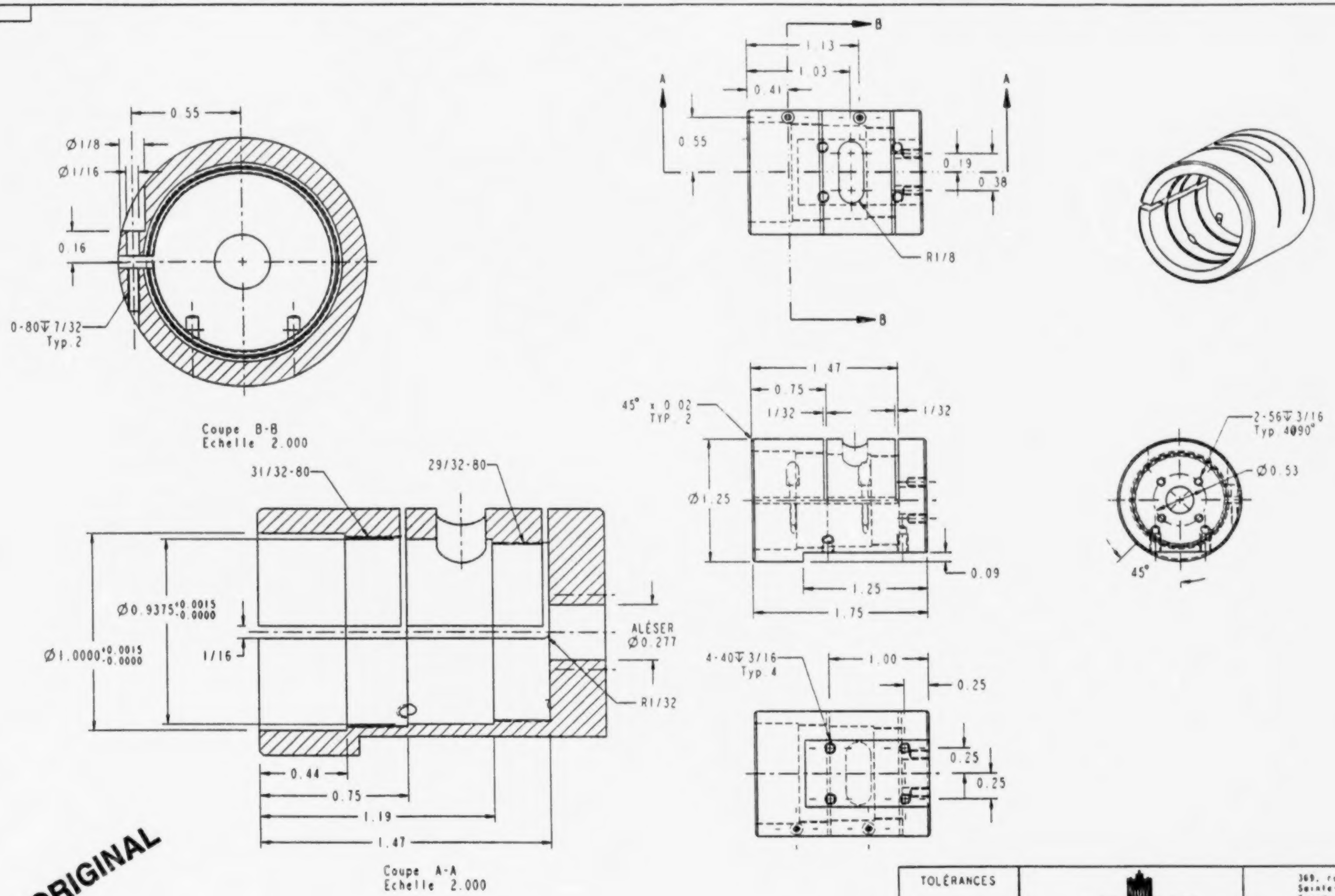
369, rue Franquet
Sainte-Foy, Québec
Canada G1P 4N8
TÉL. : (418) 657-7006
FAX : (418) 657-7009

Cellule #2

CONCU : N. Desnoyers | DESSINÉ : L. Simard | APPROUVÉ : A. Morin

QUANTITÉ : 1 | ÉCHELLE : 2:1 | DATE : 07/23 | FEUILLE de | VÉRIFIÉ :

MATÉRIEL : Aluminium anodise noir | 9707 | 7737 | 00004 | FORMAT A


0.55
Ø1/8
Ø1/16
0.16
0-80∇7/32
Typ.2
Coupe B-B
Echelle 2.000
31/32-80
29/32-80
Ø0.9375 +0.0015 -0.0000
Ø1.0000 +0.0015 -0.0000
1/16
ALÉSER
Ø0.277
R1/32
0.44
0.75
1.19
1.47
Coupe A-A
Echelle 2.000
B
1.13
1.03
0.41
A
0.55
0.19
0.38
R1/8
B
1.47
0.75
1/32
1/32
45° x 0.02
TYP. 2
Ø1.25
0.09
1.25
1.75
4-40∇3/16
Typ 4
1.00
0.25
0.25
0.25
2-56∇3/16
Typ 4090°
Ø0.53
45°

ORIGINAL

TOLÉRANCES	
x/x	± 1/32"
.x	± .010"
.xx	± .005"
.xxx	± .002"
Angle à 90°	± 1/2°
Fini de surface	32

INO NOI

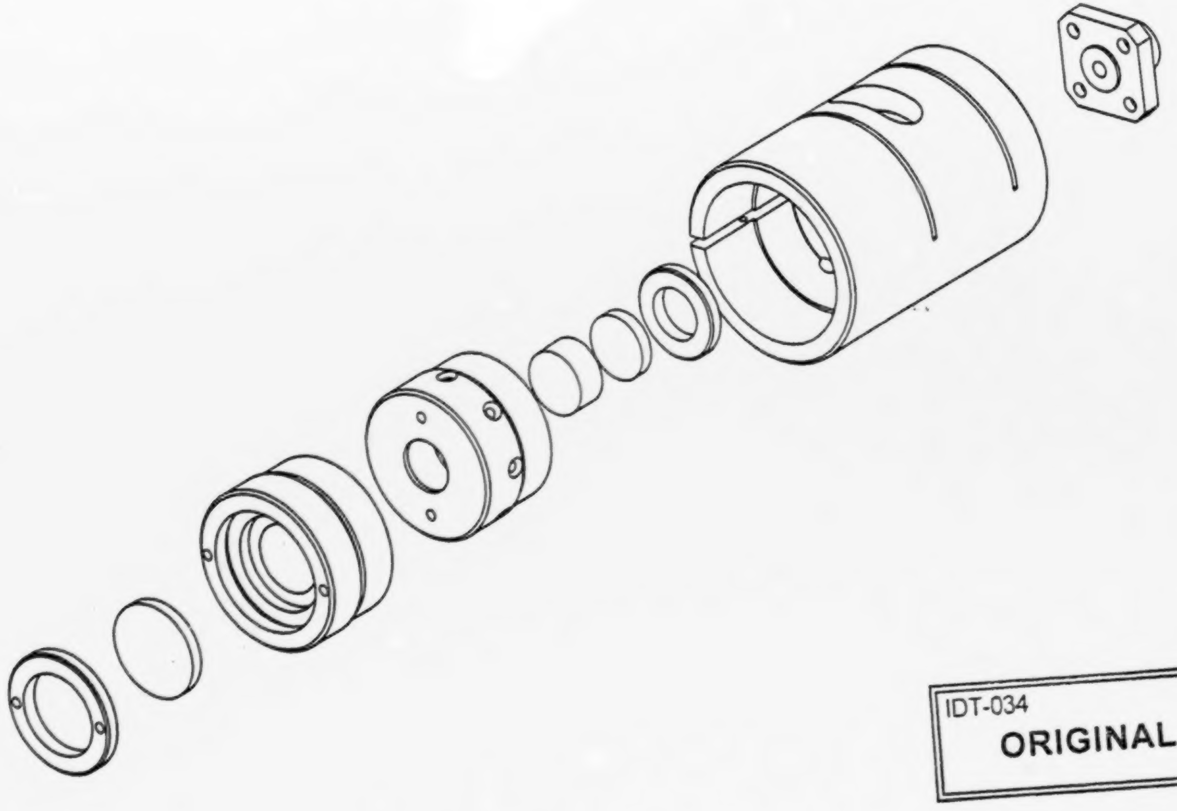
369, rue Franquet
Sainte-Foy, Québec
Canada G1P 4N8
TÉL. : (418) 657-7006
FAX : (418) 657-7009

Tube du canal d'illumination

CONÇU N. Desnoyers	DESSINÉ N. Desnoyers	APPROUVÉ A. Morin
QUANTITÉ 1 ÉCHELLE 1:1	DATE 07/23 FEUILLE de	VÉRIFIÉ

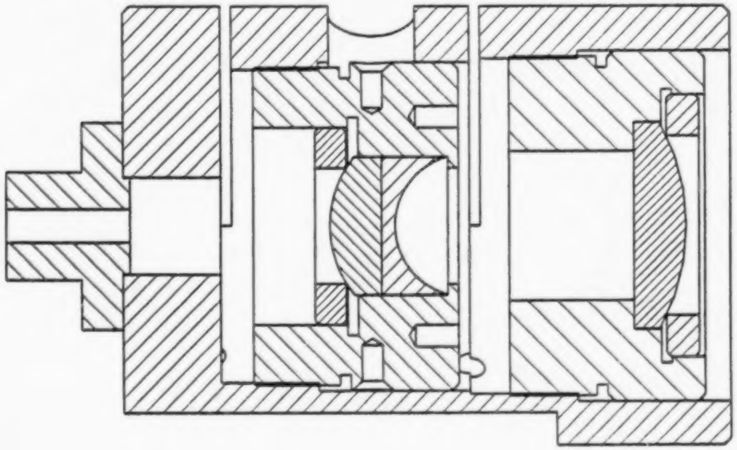
MATÉRIEL Aluminium anodisé noir	9707	7737	00005	FORMAT B

9707 | 7737 | 01000



IDT-034
ORIGINAL

TOLÉRANCES x/x ± 1/32 .x ± .010 .xx ± .005 .xxx ± .002 Angle à 90° ± 1/2° Fini de surface	INO NOI		369, rue Franquet Sainte-Foy, Québec Canada G1P 4N8 TÉL: (418) 657-7006 FAX: (418) 657-7009
	CANAL D'ILLUMINATION		
	CONÇU: N. Desnoyers	DESSINÉ: L. Simard	VÉRIFIÉ:
			APPROUVÉ: P.A
	QUANTITÉ: 1	ÉCHELLE: 1:1	FEUILLE: 1 de 2
			DATE: 97/07/24
	MATÉRIEL:		970 773 100 FORMAT



IDT-034
ORIGINAL

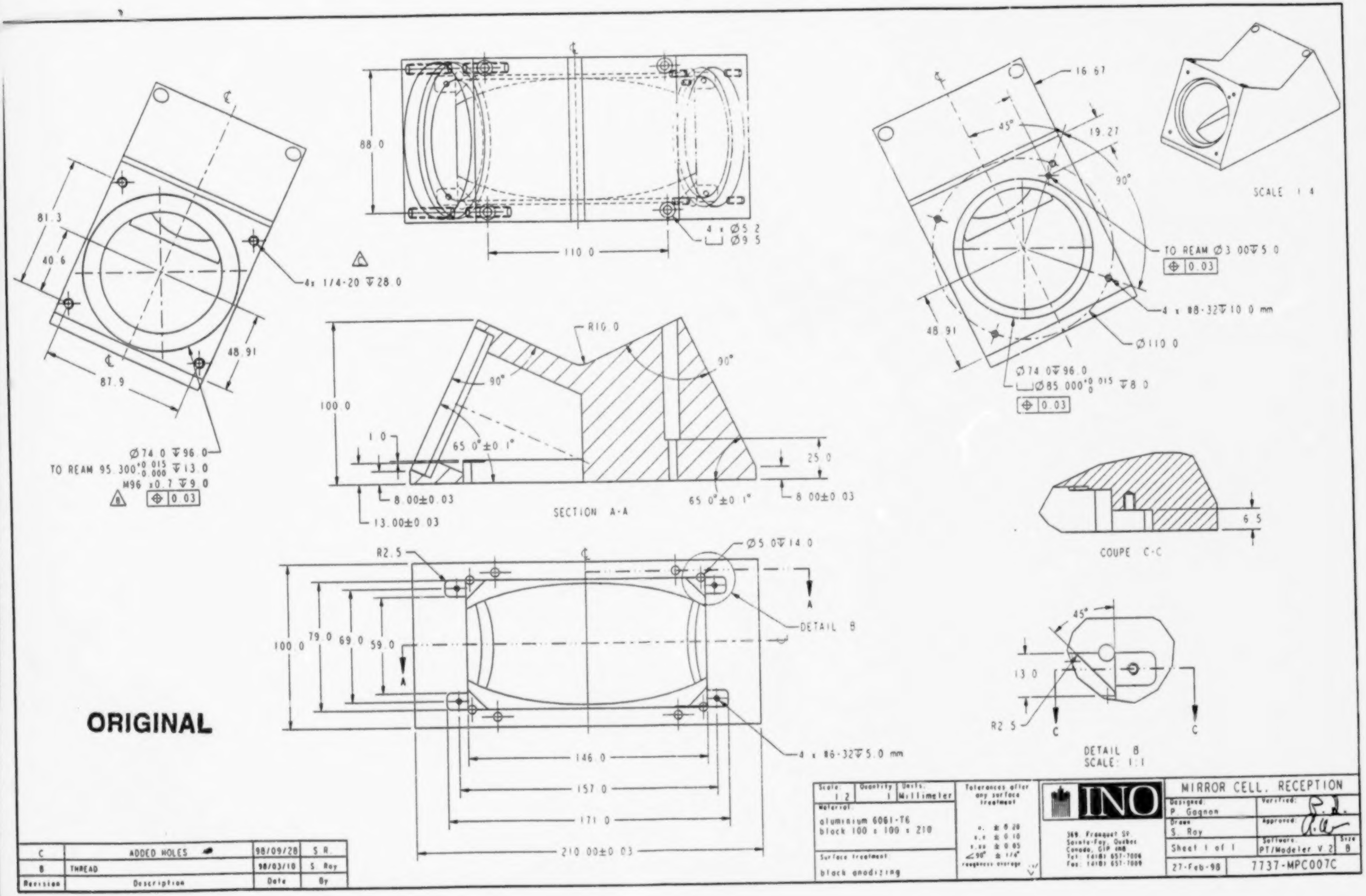
TOLÉRANCES		
x/x	±	1/32
.x	±	.010
.xx	±	.005
.xxx	±	.002
Angle à 90°	±	1/2°
Fini de surface		$\sqrt{}^{63}$

INO NOI

369, rue Franquet
Sainte-Foy, Québec
Canada G1P 4N8
TÉL: (418) 657-7006
FAX: (418) 657-7009

CANAL D'ILLUMINATION

CONÇU: N. Desnoyers	DESSINÉ: L. Simard	VÉRIFIÉ:	APPROUVÉ:
QUANTITÉ: 1	ÉCHELLE: 1:2	FEUILLE: 2 de 2	DATE: 97/07/24
MATÉRIEL: -		9707 | 7737	01000 | FORMAT A


88.0
110.0
4 x Ø5.2
⌴ Ø9.5
4x 1/4-20 ↧28.0
81.3
40.6
87.9
48.91
Ø74.0 ↧96.0
TO REAM 95.300 +0.015/-0.000 ↧13.0
M96 x0.7 ↧9.0
⌖ 0.03
B
R10.0
90°
90°
100.0
1.0
65.0°±0.1°
8.00±0.03
13.00±0.03
SECTION A-A
65.0°±0.1°
25.0
8.00±0.03
16.67
45°
19.27
90°
TO REAM Ø3.00↧5.0
⌖ 0.03
4 x #8-32↧10.0 mm
Ø110.0
48.91
Ø74.0↧96.0
⌴Ø85.000 +0.015/0 ↧8.0
⌖ 0.03
SCALE 1:4
COUPE C-C
6.5
R2.5
Ø5.0↧14.0
A
A
DETAIL B
100.0
79.0
69.0
59.0
146.0
157.0
171.0
210.00±0.03
4 x #6-32↧5.0 mm
45°
13.0
R2.5
C
C
DETAIL B
SCALE: 1:1

ORIGINAL

Revision	Description	Date	By
C	ADDED HOLES	98/09/28	S.R.
B	THREAD	98/03/10	S. Roy

Scale:	Quantity:	Units:
1:2	1	Millimeter

Material:
aluminium 6061-T6
block 100 x 100 x 210

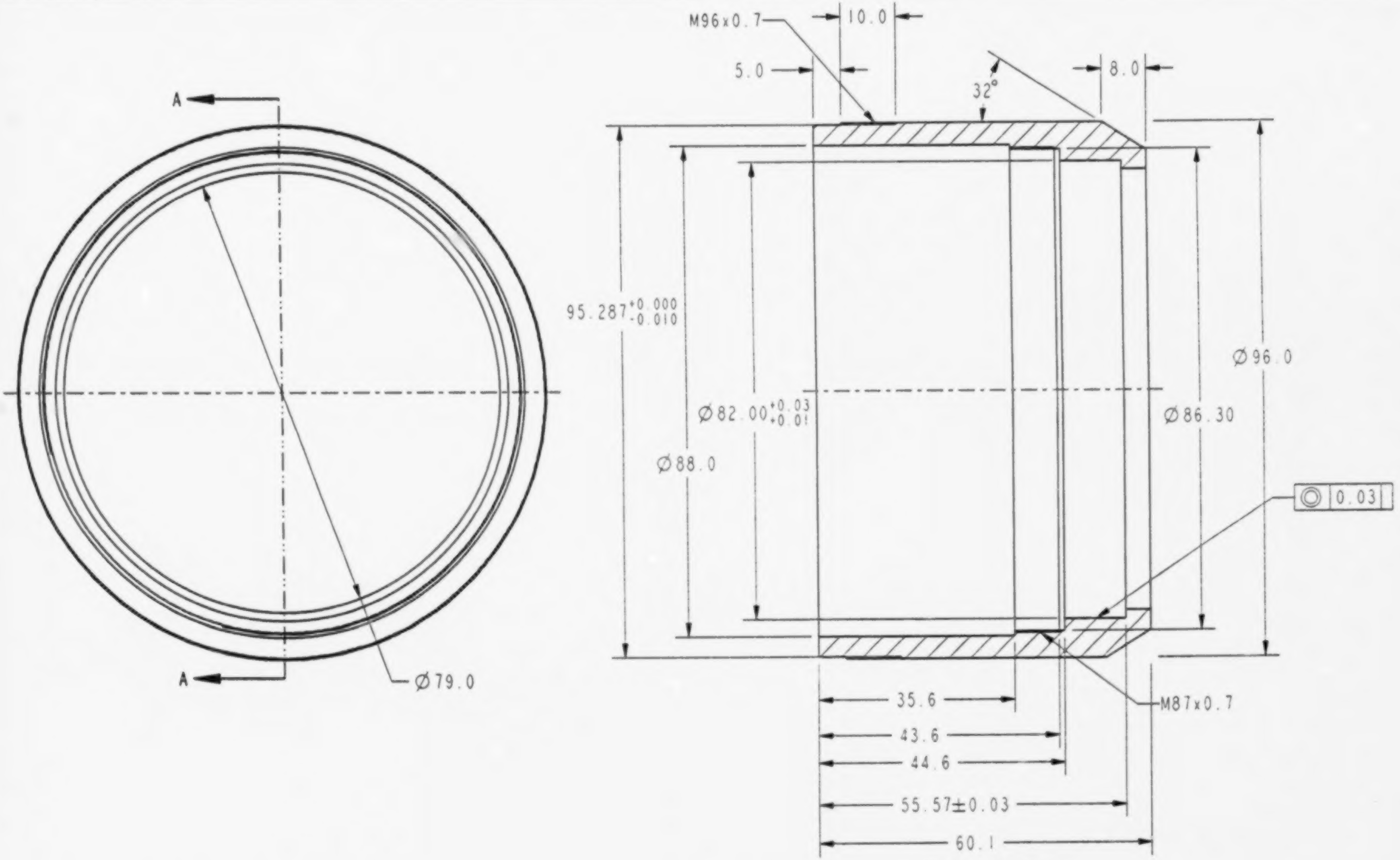
Surface treatment:
black anodizing

Tolerances after any surface treatment
x. ± 0.20
x.x ± 0.10
x.xx ± 0.05
∠90° ± 1/4°
roughness average $\sqrt{}$

INO
369, Franquet St.
Sainte-Foy, Quebec
Canada, G1P 4N8
Tel: (418) 657-7006
Fax: (418) 657-7009

MIRROR CELL, RECEPTION

Designed: P. Gagnon	Verified: P. L.
Drawn: S. Roy	Approved: A. Ch
Sheet 1 of 1	Software: PT/Modeler V 2 — Size: B
27-Feb-98	7737-MPC007C


M96x0.7
10.0
5.0
32°
8.0
A
A
95.287 +0.000 -0.010
Ø82.00 +0.03 +0.01
Ø88.0
Ø96.0
Ø86.30
0.03
Ø79.0
35.6
43.6
44.6
55.57±0.03
60.1
M87x0.7

COUPE A-A

IDT-034
ORIGINAL

Scale: 1:1	Quantity: 1	Units: Millimeter
Material: aluminium 6061-T6 shaft Ø96 x 60.1		
Surface treatment: black anodizing		

Tolerances after any surface treatment

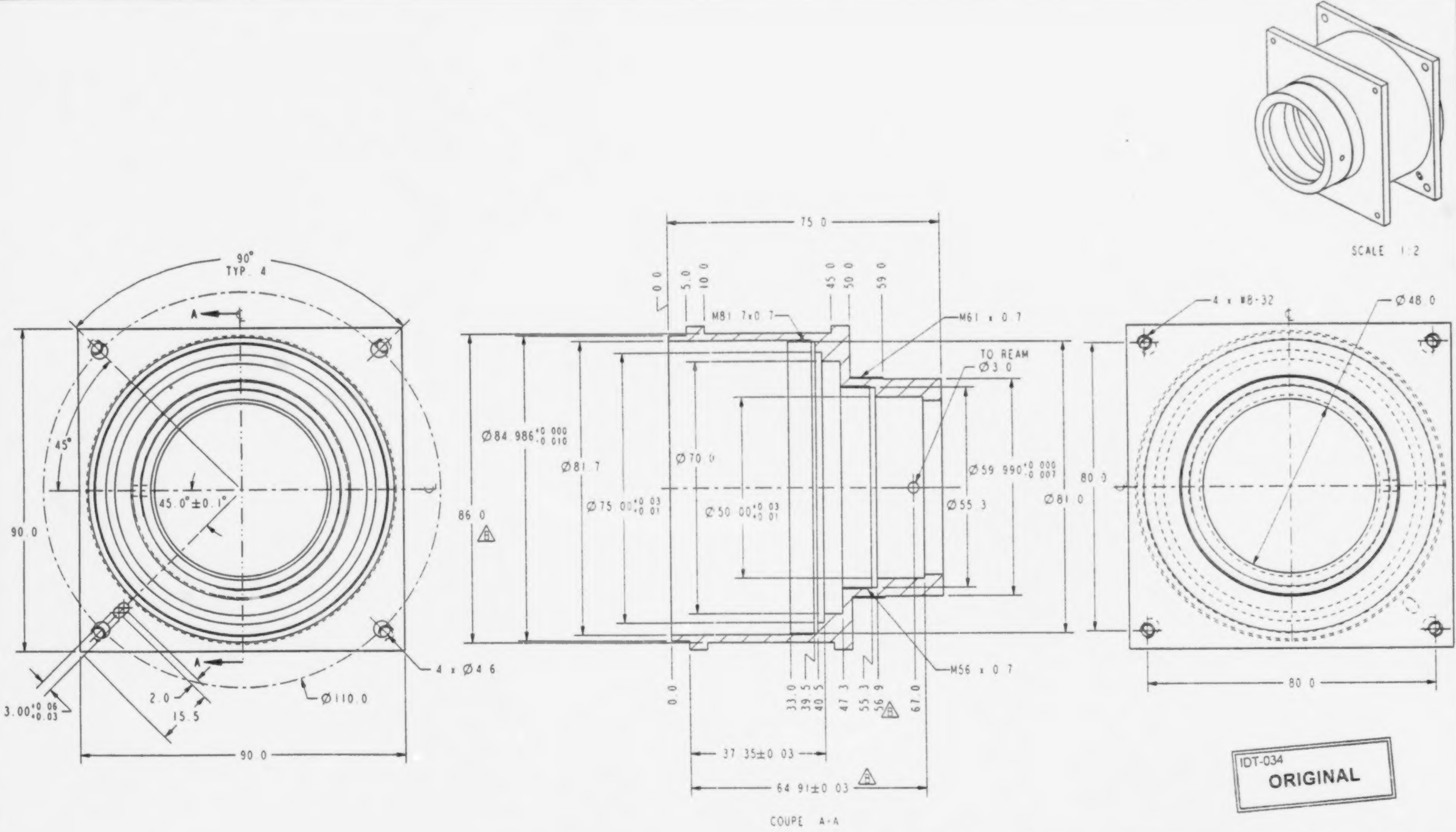
x. ± 0.20
x.x ± 0.10
x.xx ± 0.05
∠90° ± 1/4°
roughness average: 1.6 √

INO

369, Franquet St.
Sainte-Foy, Québec
Canada, G1P 4N8
Tel: (418) 657-7006
Fax: (418) 657-7009

HOUSING #1, RECEPTION		
Designed: P. Gagnon	Verified:	
Drawn: S. Roy	Approved:	
Sheet 1 of 1	Software: PT/Modeler V.2	Size A
27-Feb-98	7737-MPC008A	

vision	Description	Date	By


SCALE 1:2
90°
TYP. 4
A
45°
45.0°±0.1°
90.0
90.0
3.00+0.06 +0.03
2.0
15.5
Ø110.0
4 x Ø4.6
75.0
0.0
5.0
10.0
45.0
50.0
59.0
M81.7x0.7
M61 x 0.7
TO REAM
Ø3.0
Ø84.986+0.000 -0.010
Ø81.7
Ø70.0
Ø75.00+0.03 +0.01
Ø50.00+0.03 +0.01
Ø59.990+0.000 -0.007
Ø55.3
80.0
Ø81.0
86.0
B
M56 x 0.7
0.0
33.0
39.5
40.5
47.3
55.3
56.9
67.0
37.35±0.03
64.91±0.03
COUPE A-A
4 x #8-32
Ø48.0
80.0

IDT-034
ORIGINAL

Scale	Quantity	Units
1:1	1	Millimeter

Material
aluminium 6061-T6
block 75 x 90 x 90

Surface treatment
black anodizing

Tolerances after any surface treatment

x ± 0.20
x.x ± 0.10
x.xx ± 0.05
∠90° ± 1/4°
roughness average

INO

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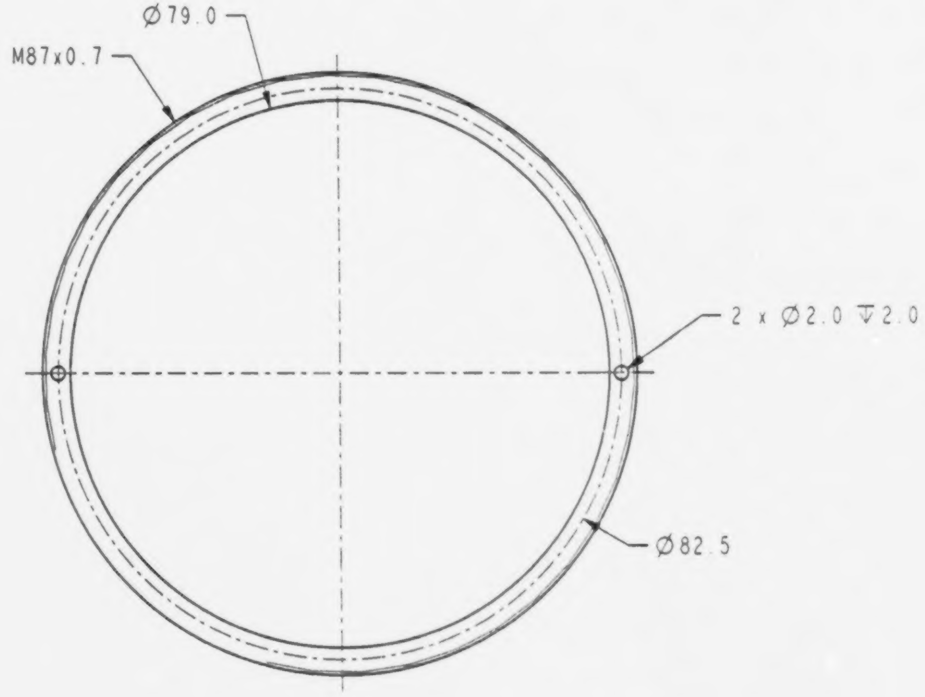
Fax (418) 657-7009

HOUSING #2, RECEPTION

Designed P. Gagnon	Verified
Drawn S. Roy	Approved
Sheet 1 of 1	Software PT/Modeler V 2
Size	B
27-Feb-98	7737-MPC009B

Revision	Description	Date	By
B	DIMENSIONS MODIFIED	98/04/14	S. Roy



IDT-034
ORIGINAL

evision	Description	Date	By

Scale: 1:1
Quantity: 1
Units: Millimeter
Material: aluminium 6061-T6
shaft Ø87 x 5.0
Surface treatment: black anodizing

Tolerances after any surface treatment
x. ± 0.20
x.x ± 0.10
x.xx ± 0.05
∠90° ± 1/4°
roughness average: 1.6 √

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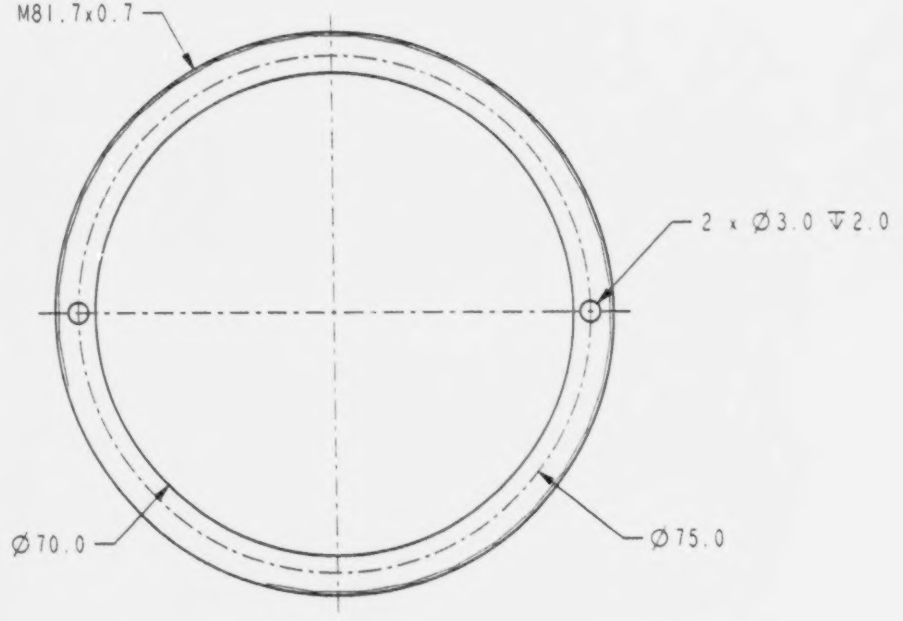
HOLDING RING #1, RECEPTION

Designed: P. Gagnon
Verified:
Drawn: S. Roy
Approved:
Sheet 1 of 1
Software: PT/Modeler V.2
Size: A
27-Feb-98
7737-MPC010A



IDT-034

ORIGINAL

Scale:	Quantity:	Units:
1:1	1	Millimeter

Material:
aluminium 6061-T6
shaft Ø81.7 x 5.0

Surface treatment:
bla[redacted]odiz[redacted]

Tolerances after any surface treatment

x.	± 0.20
x.x	± 0.10
x.xx	± 0.05
∠90°	± 1/4°

rough[redacted]erage:

INO

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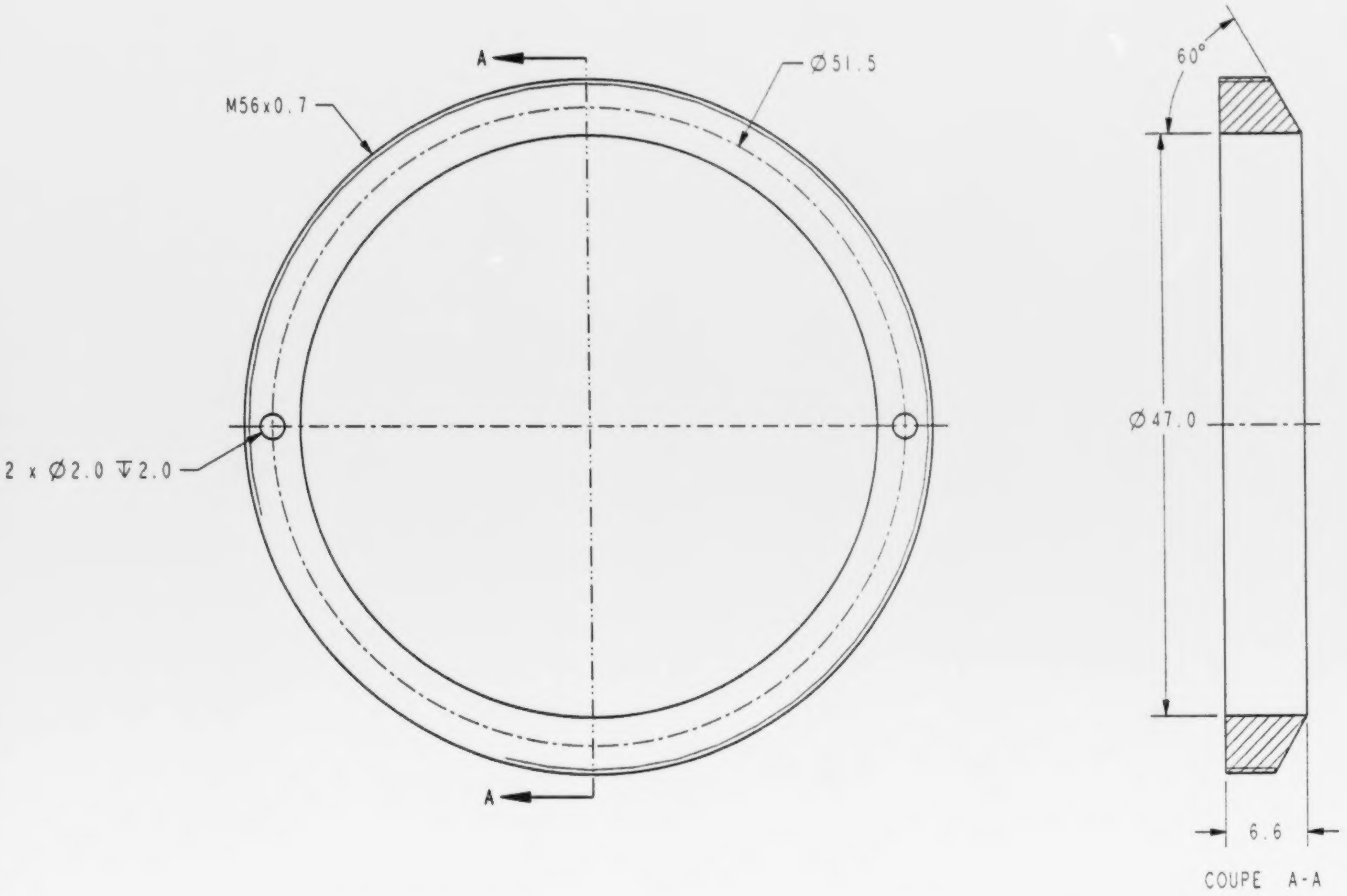
Tel: (418) 657-7006
F[redacted]8) 657[redacted]

HOLDING RING #2, RECEPTION

Designed: P. Gagnon	Verified:
Drawn: S. Roy	Approved:
Sheet 1 of 1	Software: PT/Modeler V.2 — Size: A

evi[redacted] [redacted] D[redacted]tion[redacted] [redacted] Da[redacted] B[redacted] [redacted] [redacted] [redacted] [redacted] [redacted] [redacted]eb-9[redacted] 7[redacted]MPO[redacted]A [redacted]



IDT-034
ORIGINAL

Scale: 2:1	Quantity: 1	Units: Millimeter
Material: aluminium 6061-T6 shaft Ø56 x 6.6		
Surface treatment: black anodizing		

Tolerances after any surface treatment
x. ± 0.20
x.x ± 0.10
x.xx ± 0.05
∠90° ± 1/4°
roughness average √

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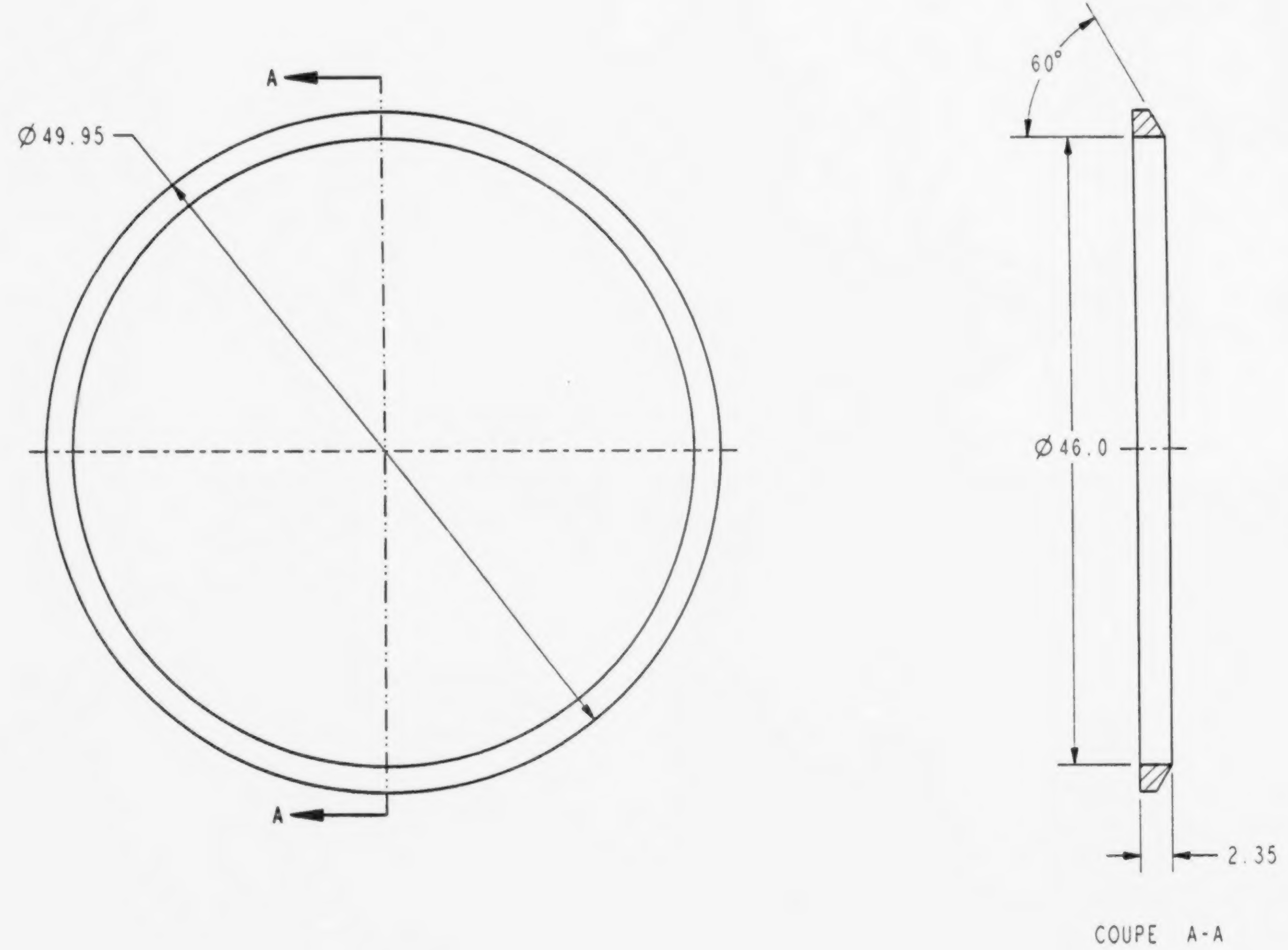
HOLDING RING #3, RECEPTION		
Designed: P. Gagnon	Verified:	
Drawn: S. Roy	Approved:	
Sheet 1 of 1	Software: PT/Modeler V.2	Size A
27-Feb-98	7737-MPC012A	

vision	Description	Date	By



COUPE A-A

IDT-034
ORIGINAL

Scale: 2:1	Quantity: 1	Units: Millimeter

Material:
aluminium 6061-T6
shaft Ø50 x 2.3

Surface treatment:
blac odiz

Tolerances after any surface treatment
x. ± 0.20
x.x ± 0.10
x.xx ± 0.05
∠90° ± 1/4°
roughness average:

INO

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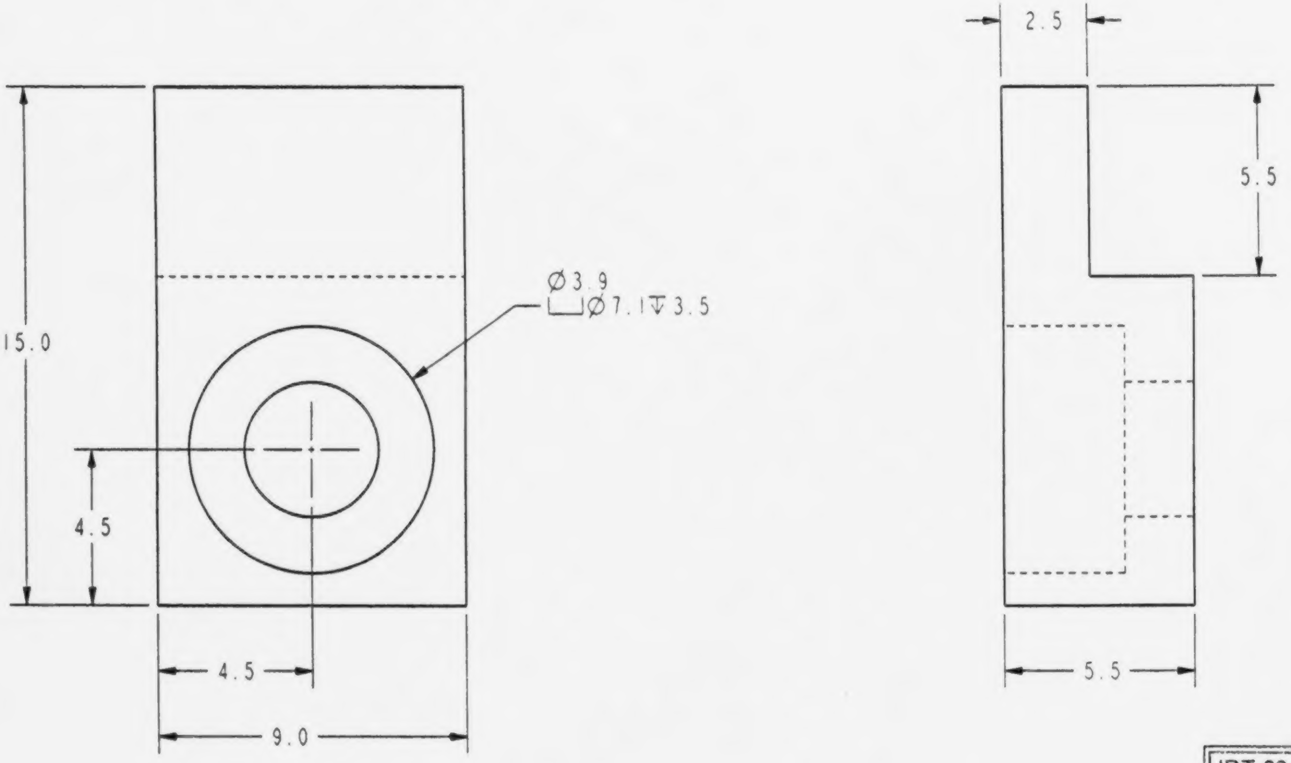
SPACER, RECEPTION

Designed: P. Gagnon	Verified:
Drawn: S. Roy	Approved:
Sheet 1 of 1	Software: PT/Modeler V.2 — Size A
eb-9	7 MPC A

evision — Description — Da — B

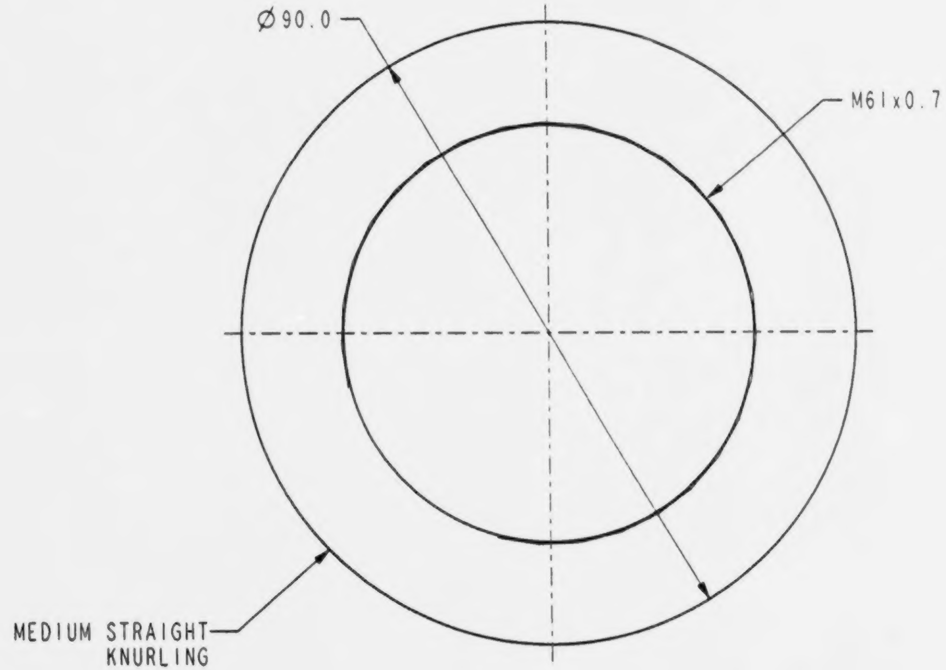


IDT-034
ORIGINAL

Scale: 5:1	Quantity: 4	Units: Millimeter	Tolerances after any surface treatment x. ± 0.20 x.x ± 0.10 x.xx ± 0.05 ∠90° ± 1/4° roughness average: 1.6 √	INO 369, Franquet St. Sainte-Foy, Québec Canada, G1P 4N8 Tel: (418) 657-7006 Fax: (418) 657-7009
Material: delrin pl. 5.5 x 9 x 15				
Surface treatment: none				

MIRROR SUPPORT BLOCK, RECEP.	
Designed: P. Gagnon	Verified:
Drawn: S. Roy	Approved:
Sheet 1 of 1	Software: PT/Modeler V.2
	Size A
27-Feb-98	7737-MPC016A

evision	Description	Date	By



IDT-034
ORIGINAL

Scale: 1:1	Quantity: 1	Units: Millimeter
Material: aluminium 6061-T6 shaft Ø90 x 9.0		
Surface treatment: blac[redacted]diz[redacted]		

Tolerances after any surface treatment
x. ± 0.20
x.x ± 0.10
x.xx ± 0.05
∠90° ± 1/4°
roughness average: [redacted]

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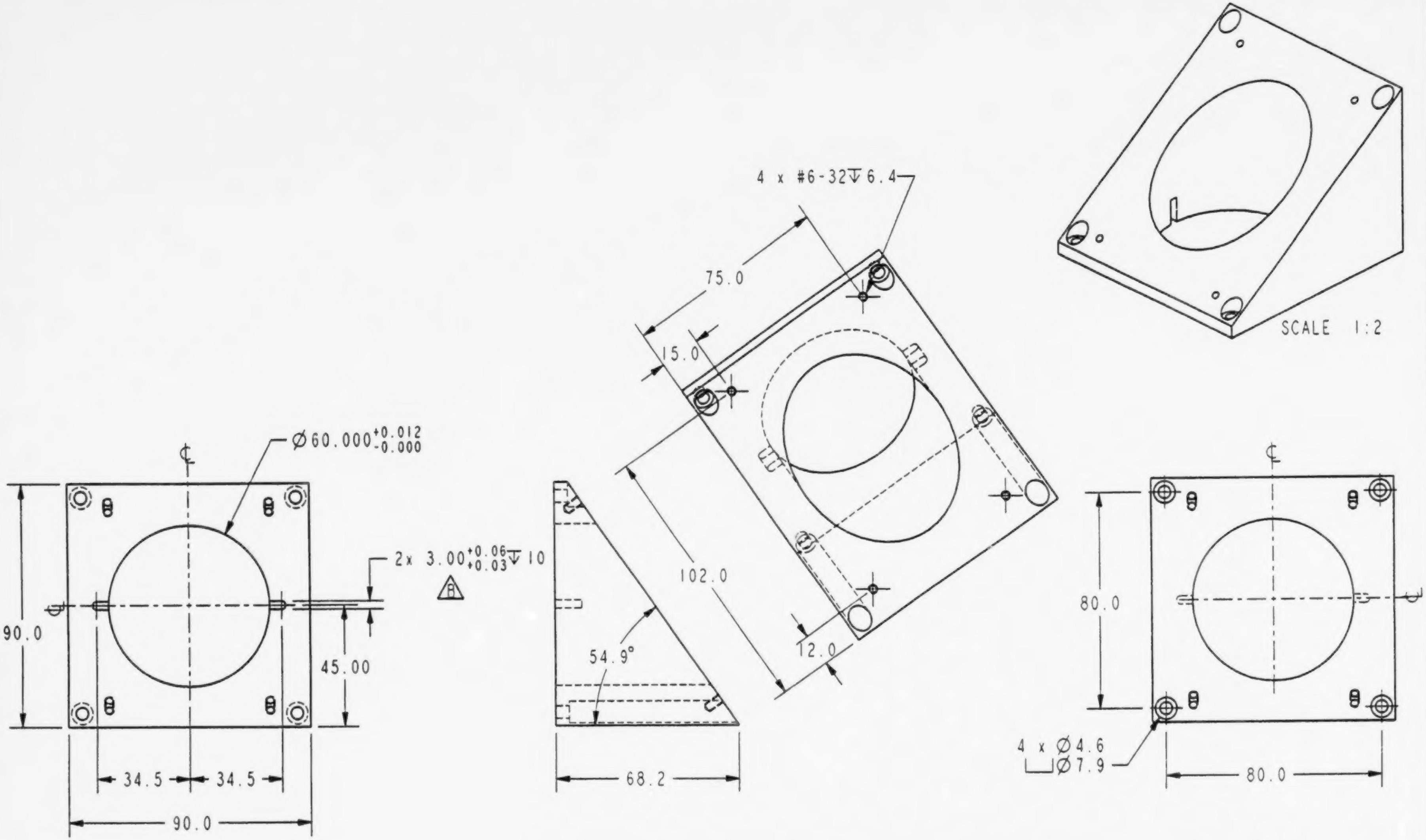
Tel: (418) 657-7006
Fa[redacted] 657-70[redacted]

Z ADJUSTEMENT RING, RECEP.

Designed: P. Gagnon	Verified:	
Drawn: S. Roy	Approved:	
Sheet 1 of 1	Software: PT/Modeler V.2	Size A

[redacted]eb-9[redacted] 7[redacted]MPC[redacted]

evis[redacted] [redacted] D[redacted]tion[redacted] [redacted] Da[redacted] By[redacted]


4 x #6-32↧6.4
75.0
15.0
102.0
12.0
SCALE 1:2
Ø60.000 +0.012 -0.000
2x 3.00 +0.06 +0.03 ↧10
B
90.0
45.00
34.5
34.5
90.0
54.9°
68.2
80.0
80.0
4 x Ø4.6
⌴Ø7.9

ORIGINAL

Revision	Description	Date	By
B	RAINURE AJOUTÉE	12/05/99	S.R.

Scale:	Quantity:	Units:
1:2	1	Millimeter

Material:
Aluminium 6061-t6
-
-

Surface treatment:
Black anodizing

Tolerances after any surface treatment
x. ± 0.20
x.x ± 0.10
x.xx ± 0.05
∠90° ± 1/4°
roughness average: 1.6/

INO

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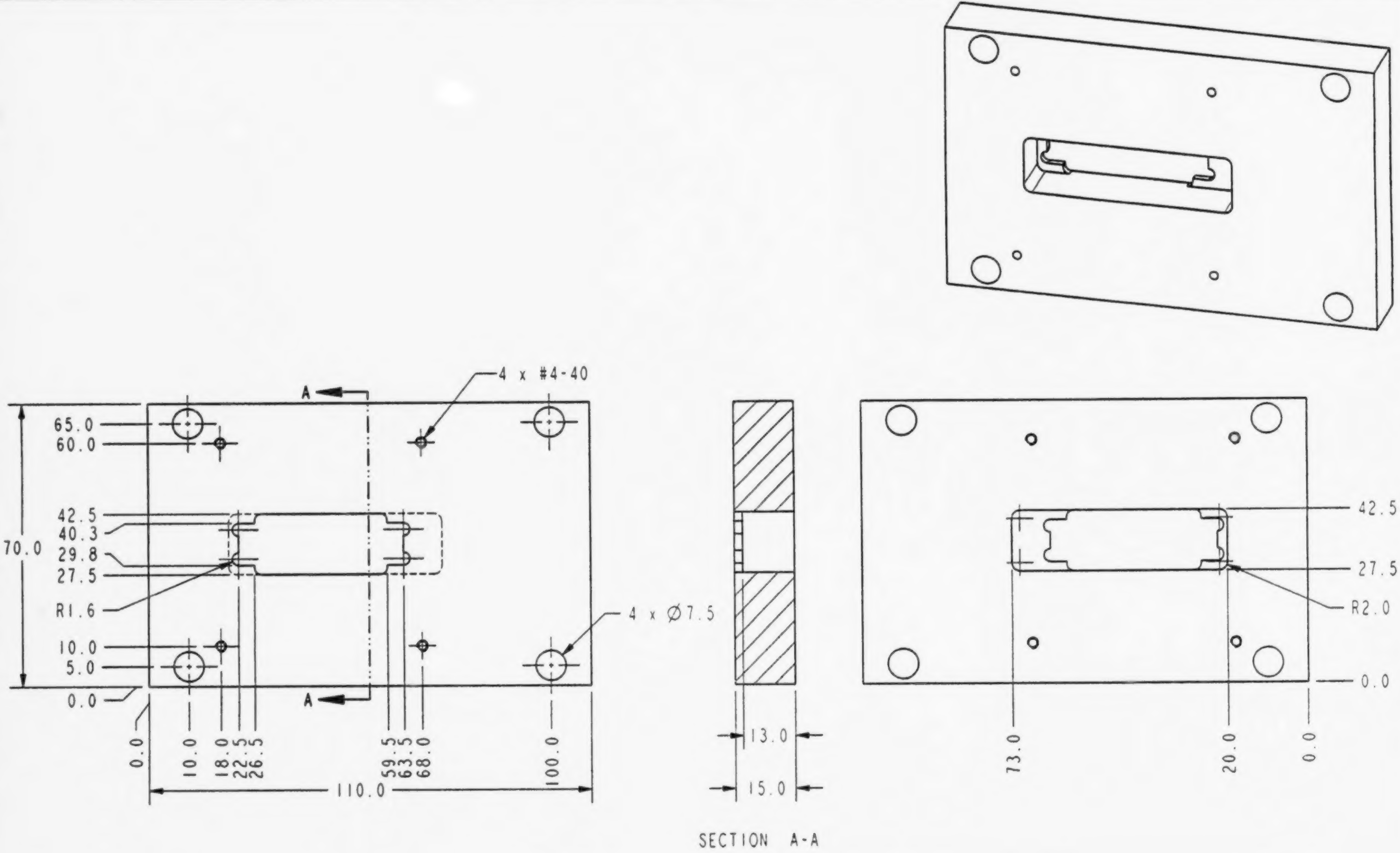
Z ADJUSTMENT #2, RECEPTION

Designed: P. Gagnon	Verified: P. A.
Drawn: L. Simard	Approved:
Sheet 1 of 1	Software: PT/Modeler V.2 — Size A
19-Aug-98	7737-MPC018B


4 x #4-40
A
A
65.0
60.0
42.5
40.3
70.0
29.8
27.5
R1.6
10.0
5.0
0.0
0.0
10.0
18.0
22.5
26.5
59.5
63.5
68.0
100.0
110.0
4 x Ø7.5
13.0
15.0
42.5
27.5
R2.0
0.0
73.0
20.0
0.0
SECTION A-A

ORIGINAL

Scale: 3:4	Quantity: 1	Units: Millimeter
Material: Aluminium 6061-T6 Pl. 15.0 -		
Surface treatment: Bl[redacted]odi[redacted]		

Tolerances after any surface treatment
x. ± 0.20
x.x ± 0.10
x.xx ± 0.05
∠90° ± 1/4°
rough[redacted]erage:

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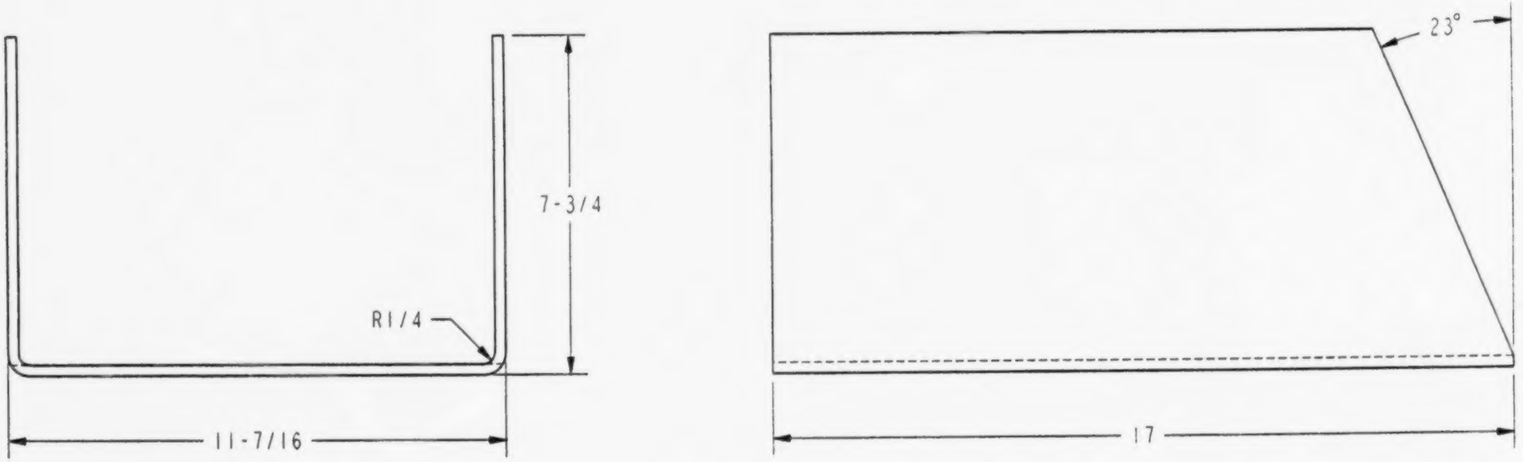
F[redacted]8) 6[redacted]

DETECTOR SUPPORT #2

Designed: P. Gagnon	Verified: P. L.
Drawn: L. Simard	Approved: MA
Sheet 1 of 1	Software: PT/Modeler V 2 — Size: A

[redacted] Aug-[redacted] 7[redacted]-MPC[redacted]R [redacted]

B	GENEAL REVIEW	27/10/98	L.S.
Rev[redacted]	[redacted] [redacted]ptio[redacted] [redacted]	D[redacted]	[redacted]



ORIGINAL

Scale: 1:4
Quantity: 1
Units: Inch
Material:
Stainless steel 316L
Pl. 1/4
-
Surface treatment:
None

Tolerances after any surface treatment
x/x ± 1/32
x.x ± 0.010
x.xx ± 0.005
x.xxx ± 0.002
∠90° ± 1/4°
roughness average: 63√

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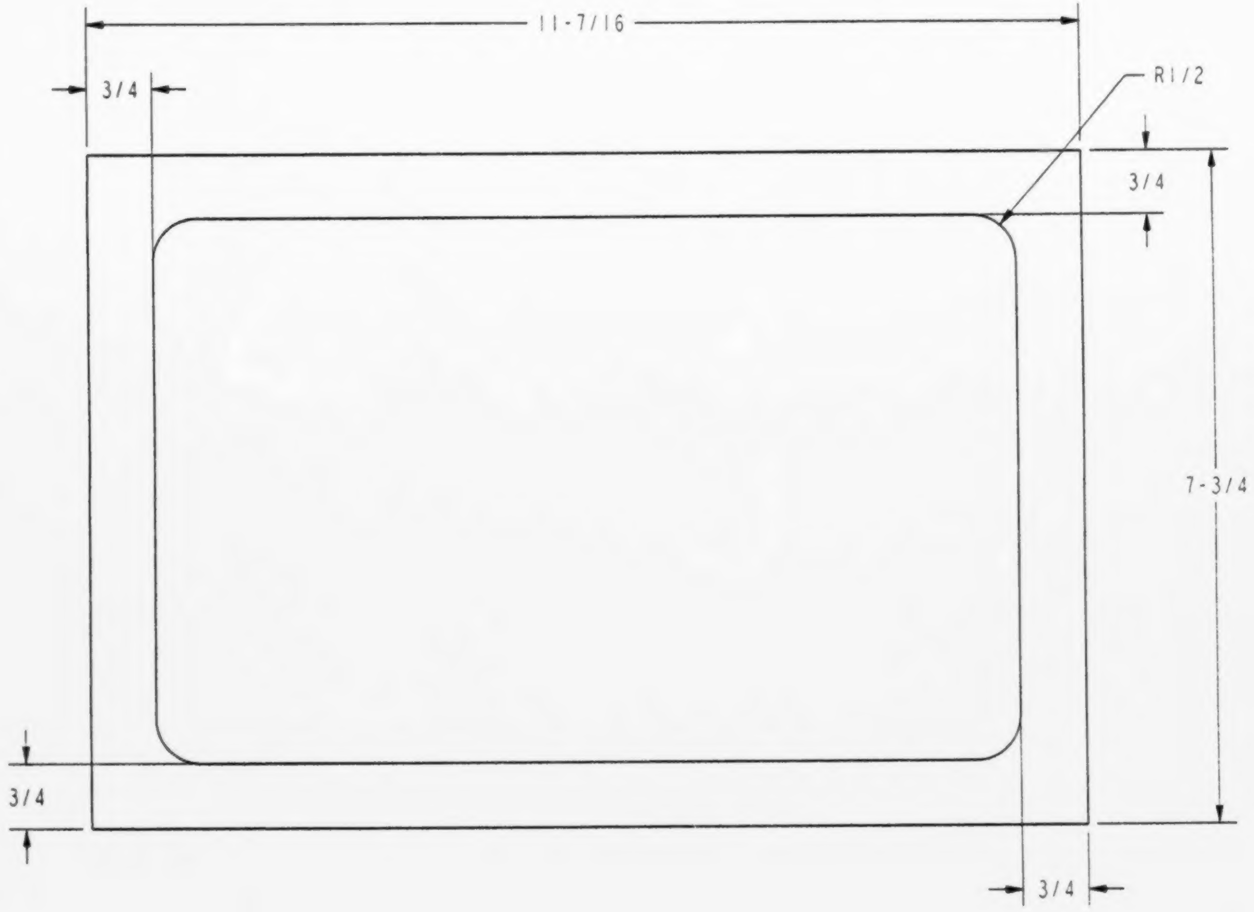
FOLDED PLATE, LEFT HOUSING
Designed: P. Gagnon
Verified: P.L.
Drawn: L. Simard
Approved: M.A.
Sheet 1 of 1
Software: Pro/E Ver. 20
Size: A
05-Aug-99
7737-MPC020A

BOITIER_PLAQUE_PLIEE_GAUCHE

evision | Description | Date | By



ORIGINAL

Scale: 1:2	Quantity: 1	Units: Inch
Material: Stainless steel 316L Pl. 3/4 -		
Surface treatment: None		

Tolerances after any surface treatment
x/x ± 1/32
x.x ± 0.010
x.xx ± 0.005
x.xxx ± 0.002
∠90° ± 1/4°
roughness average: 63/

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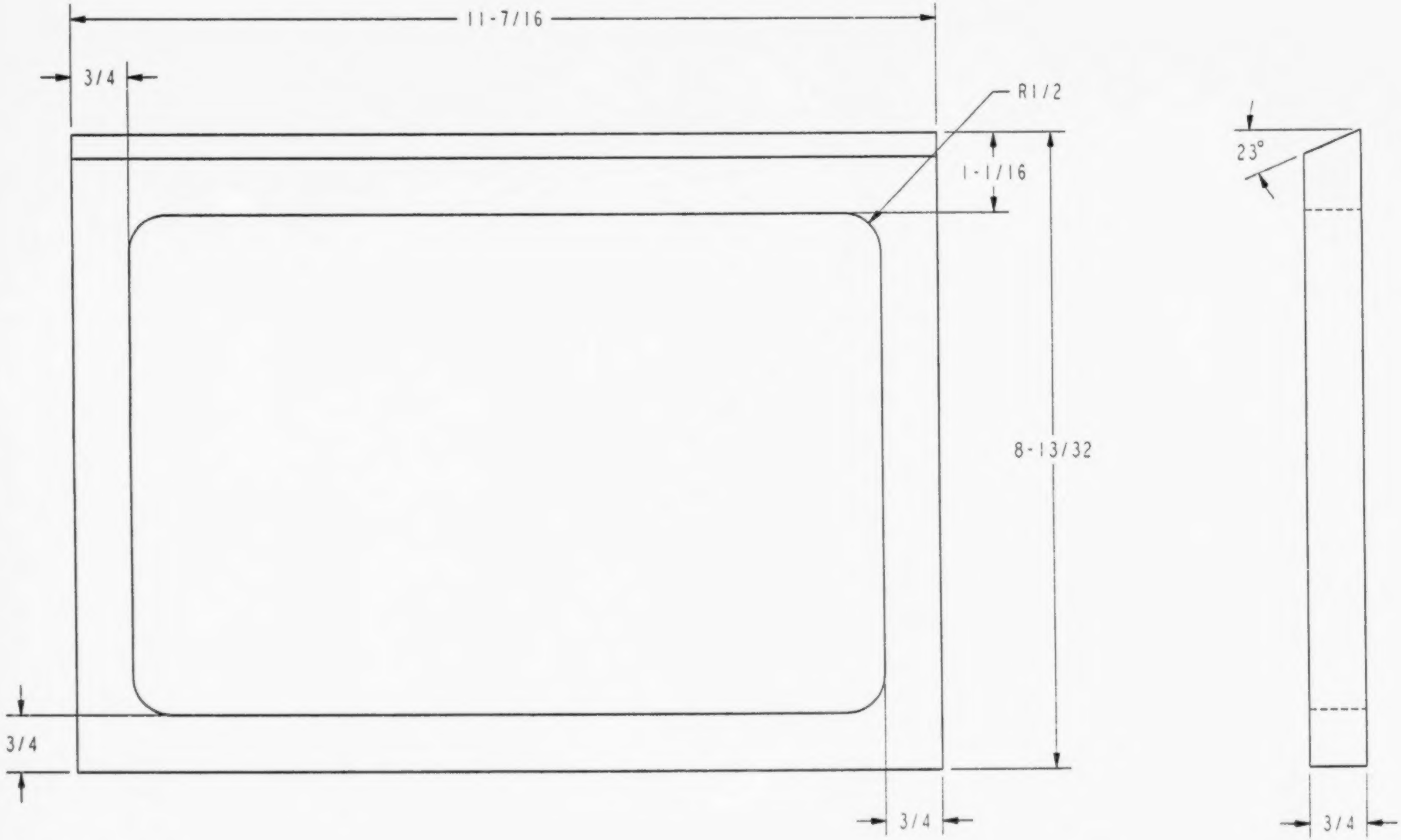
REAR PLATE, LEFT HOUSING

Designed: P. Gagnon	Verified: P.A.	
Drawn: L. Simard	Approved: M.A.	
Sheet 1 of 1	Software: Pro/E Ver. 20	Size A
05-Aug-99	7737-MPC021A	

OTTIER, PLAQUE ARRIERE, GAUCHE

evision	Description	Date	By



ORIGINAL

vision	Description	Date	By

Scale: 1:2
Quantity: 1
Units: Inch
Material:
Stainless steel 316L
-
-
Surface treatment:
None

Tolerances after any surface treatment
x/x ± 1/32
x.x ± 0.010
x.xx ± 0.005
x.xxx ± 0.002
∠90° ± 1/4°
roughness average: 63

INO

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Sainte-Foy, Québec
Canada, G1P 4N8
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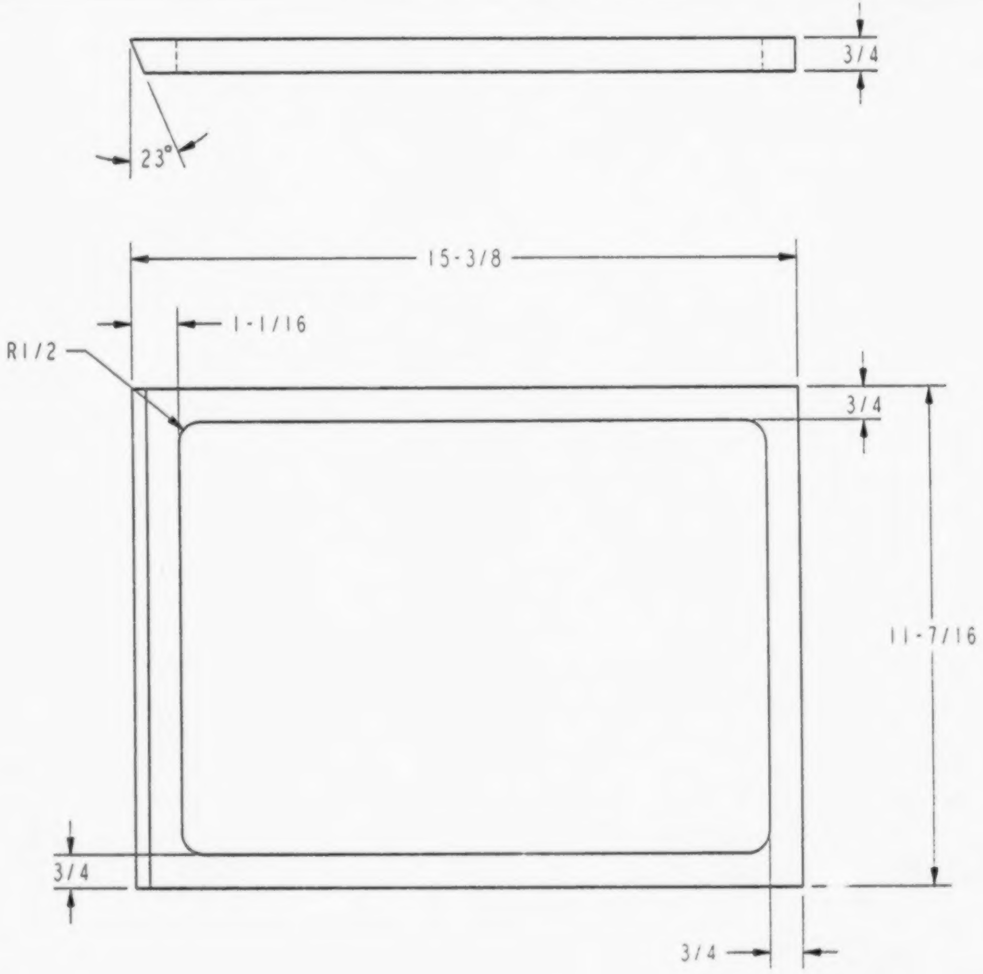
FRONT PLATE, LEFT HOUSING
Designed: P. Gagnon
Verified: P.A.
Drawn: L. Simard
Approved: M.A.
Sheet 1 of 1
Software: Pro/E Ver. 20
Size: A
05-Aug-99
7737-MPC022A
BOITIER PLAQUE AVANT GAUCHE



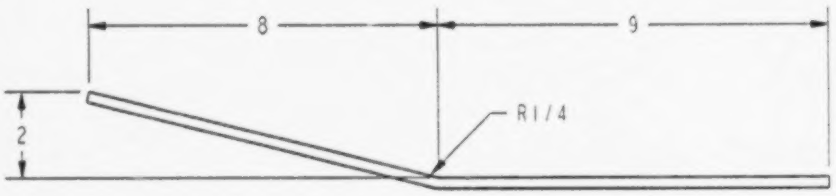
ORIGINAL

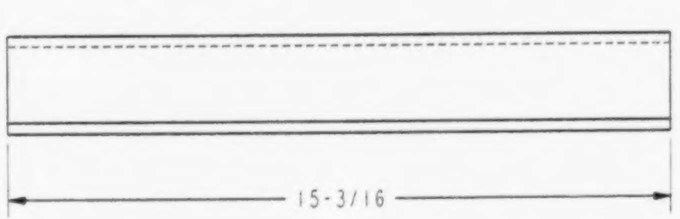
Scale: 1:4	Quantity 1	Units: Inch	Tolerances after any surface treatment	**INO**
Material: Stainless steel 316L - -			x/x ± 1/32 x.x ± 0.010 x.xx ± 0.005 x.xxx ± 0.002 ∠90° ± 1/4° roughness average: 63/	369, Franquet St. Sainte-Foy, Québec Canada, G1P 4N8 Tel: (418) 657-7006 Fax: (418) 657-7009
Surface treatment: None				

TOP FRAME, LEFT HOUSING	
Designed: P. Gagnon	Verified: P.L
Drawn: L. Simard	Approved: M.A.
Sheet 1 of 1	Software: Pro/E Ver. 20 — Size A
05-Aug-9[illegible]	7737 MPC0[illegible]A

evision	Description	Date	By

ITTER_CADRE_DESSUS_GAUCHE





ORIGINAL

vision	Description	Date	By

Scale: 1:4
Quantity: 1
Units: Inch
Material:
Stainless steel 316L
Pl. 1/4
-
Surface treatment:
None

Tolerances after any surface treatment
x/x ± 1/32
x.x ± 0.010
x.xx ± 0.005
x.xxx ± 0.002
∠90° ± 1/4°
roughness average 63/

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Sainte-Foy, Quebec
Canada, G1P 4N8
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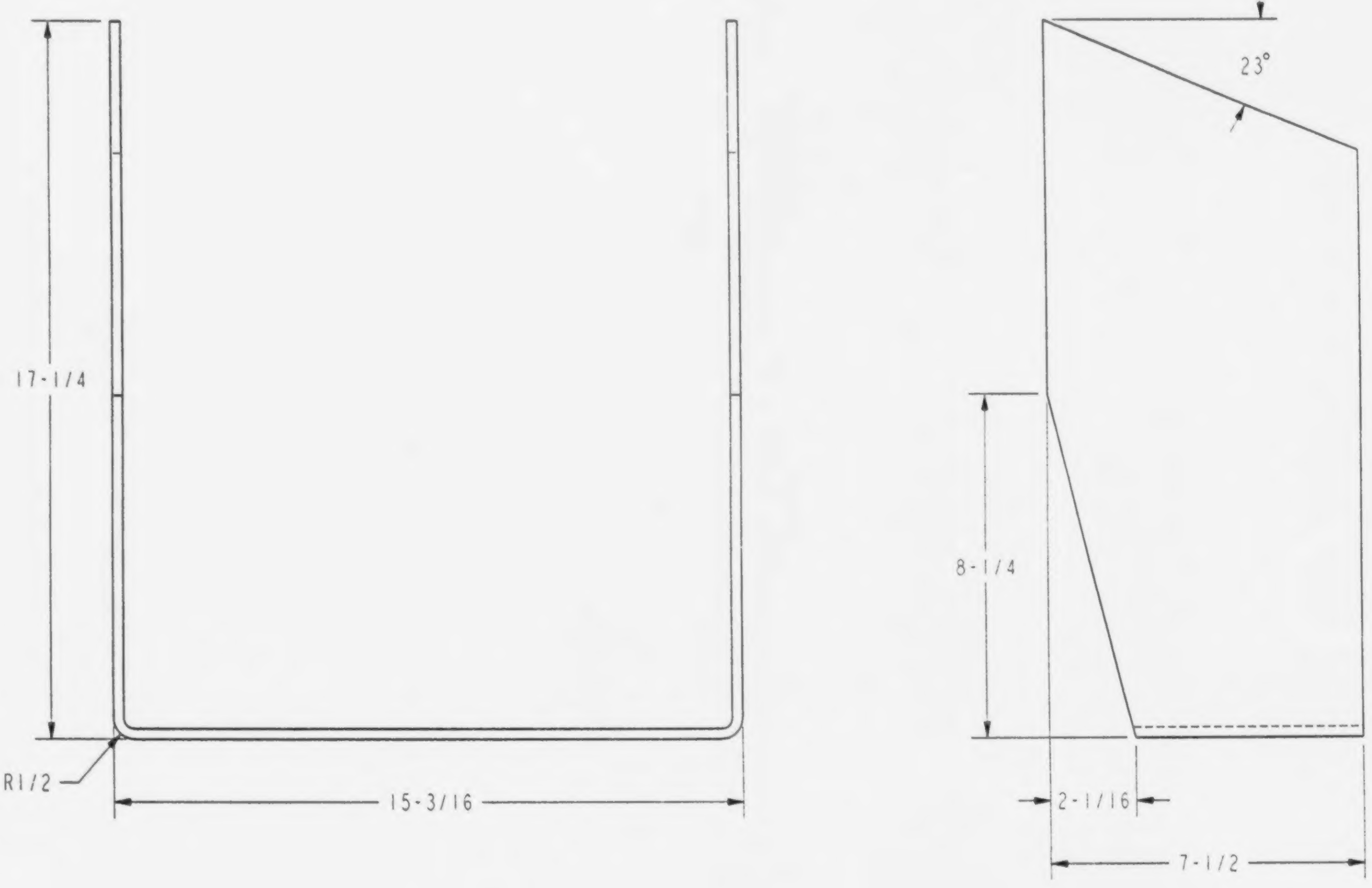
Fax: (418) 657-7009

BOTTOM FOLDED PLATE, RIGHT HOUSING
Designed: P. Gagnon
Verified: P.D.
Drawn: L. Simard
Approved: M.A.
Sheet 1 of 1
Software: Pro/E Ver. 20
Size: A
06-Aug-99
7737-MPC024A

BOTTIER_PLAQUE_PLIEE_DESSOUS



ORIGINAL

vision	Description	Date	By

Scale: 1:4
Quantity: 1
Units: Inch
Material:
Stainless steel 316L
Pl. 1/4
-
Surface treatment:
None

Tolerances after any surface treatment
x/x ± 1/32
x.x ± 0.010
x.xx ± 0.005
x.xxx ± 0.002
∠90° ± 1/4°
roughness average: 63

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Sainte-Foy, Québec
Canada, G1P 4N8
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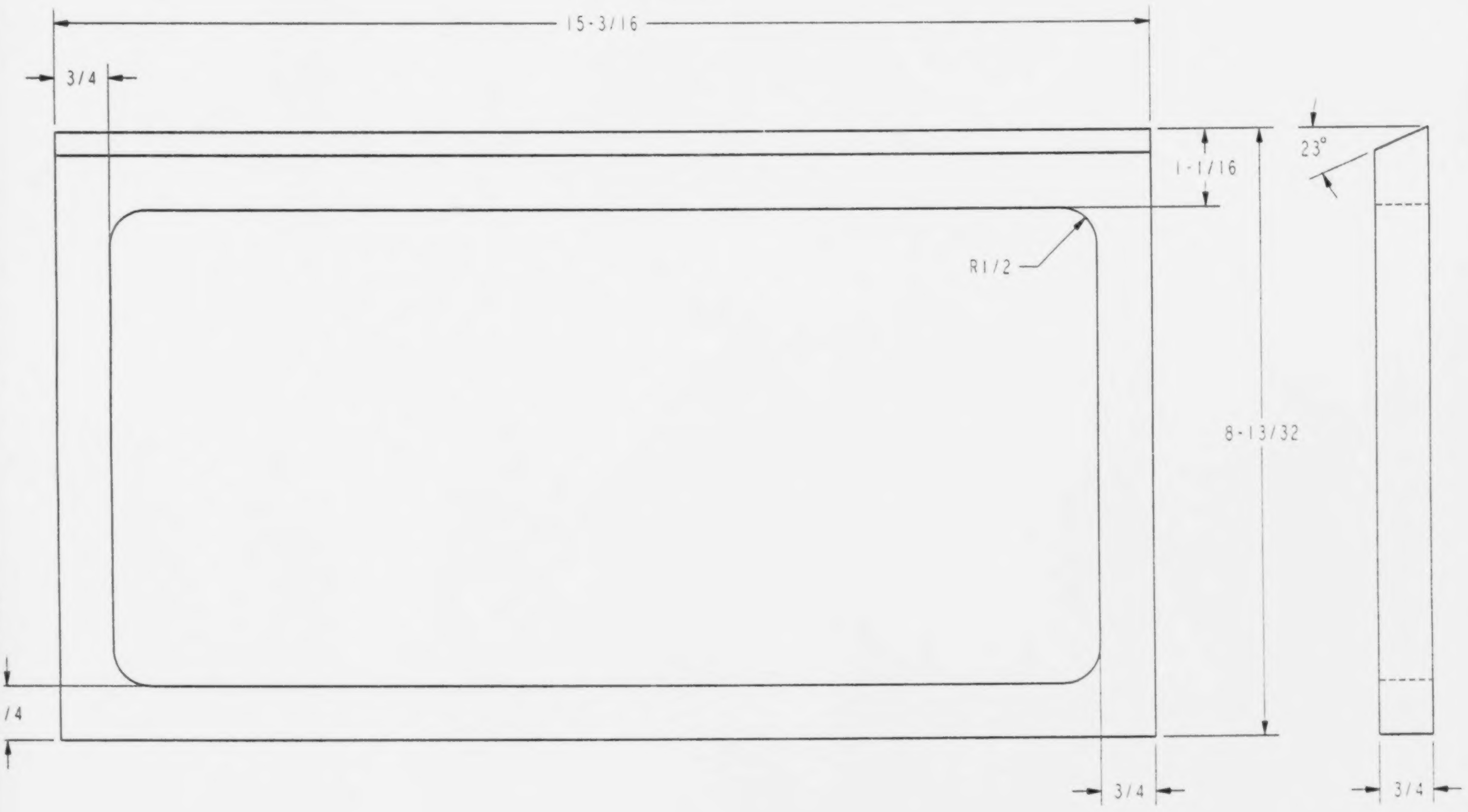
Fax: (418) 657-7009

FOLDED PLATE, RIGHT HOUSING
Designed: P. Gagnon
Verified: P.G.
Drawn: L. Simard
Approved: M.A.
Sheet 1 of 1
Software: Pro/E Ver. 20
Size A
06-Aug-99
7737-MPC025A

OITIER_PLAQUE_PLIEE_DROITE



ORIGINAL

vision	Description	Date	By

Scale 1:2
Quantity 1
Units Inch
Material
Stainless steel 316L
-
-
Surface treatment
None

Tolerances after any surface treatment
x/x ± 1/32
x.x ± 0.010
x.xx ± 0.005
x.xxx ± 0.002
∠90° ± 1/4°
roughness average: 63/√

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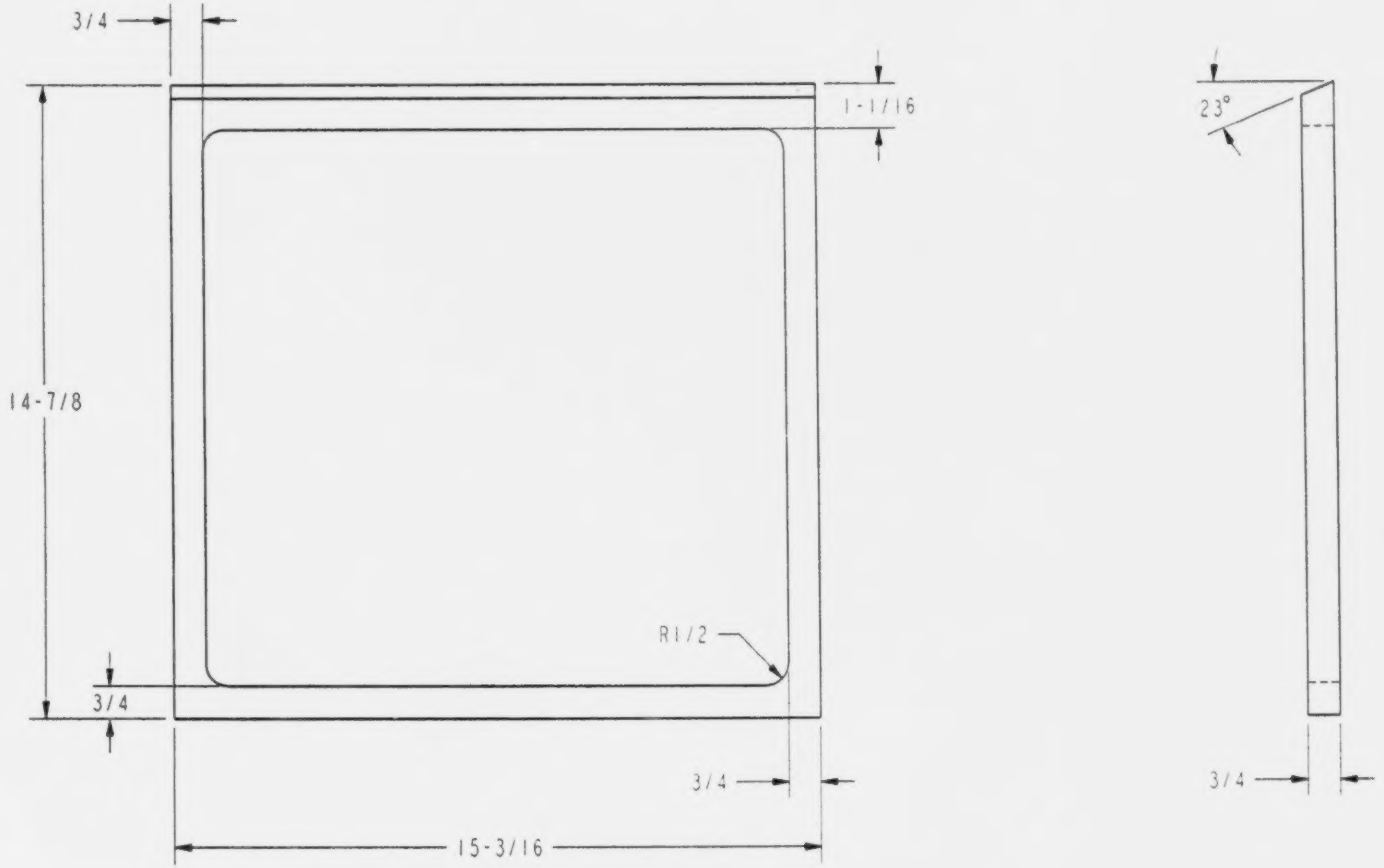
FRONT PLATE, RIGHT HOUSING
Designed: P. Gagnon
Verified: P.D.
Drawn: L. Simard
Approved: M.A.
Sheet 1 of 1
Software: Pro/E Ver. 20
Size: A
06-Aug-99
7737-MPC026A

BOITIER PLAQUE AVANT DROITE



ORIGINAL

ision	Description	Date	By

Scale:	Quantity	Units:
1 : 4	1	Inch

Material:
Stainless steel 316L
-
-

Surface treatment
None

Tolerances after
any surface
treatment
x/x ± 1/32
x.x ± 0.010
x.xx ± 0.005
x.xxx ± 0.002
∠90° ± 1/4°
roughness average: 63√

INO

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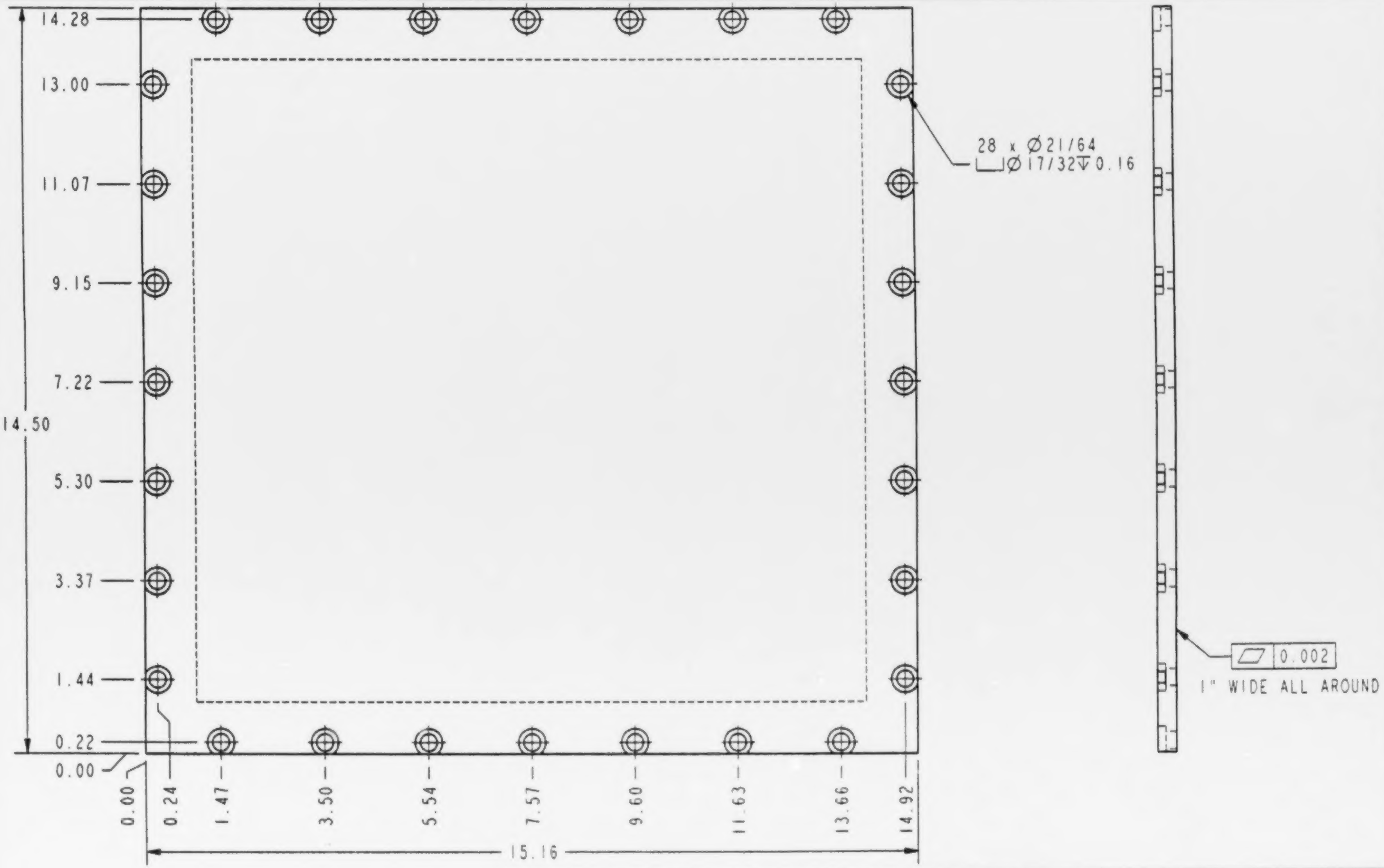
TOP FRAME, RIGHT HOUSING

Designed: P. Gagnon	Verified: P.A.
Drawn: L. Simard	Approved: M.A.
Sheet 1 of 1	Software Pro/E Ver. 20
	Size A
06-Aug-99	7737-MPC027A

TTIER CADRE DESSUS DROIT


14.28
13.00
11.07
9.15
7.22
5.30
3.37
1.44
0.22
0.00
14.50
0.00
0.24
1.47
3.50
5.54
7.57
9.60
11.63
13.66
14.92
15.16
28 x Ø21/64
⌴Ø17/32↧0.16
▱ 0.002
1" WIDE ALL AROUND

ORIGINAL

Revision	Description	Date	By

Scale: 3:8	Quantity: 1	Units: Inch
Material: Stainless steel 316L Pl. 3/8 -		
Surface treatment: None		

Tolerances after any surface treatment
x/x ± 1/32
x.x ± 0.010
x.xx ± 0.005
x.xxx ± 0.002
∠90° ± 1/4°
roughness average: 63/

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Canada, G1P 4N8
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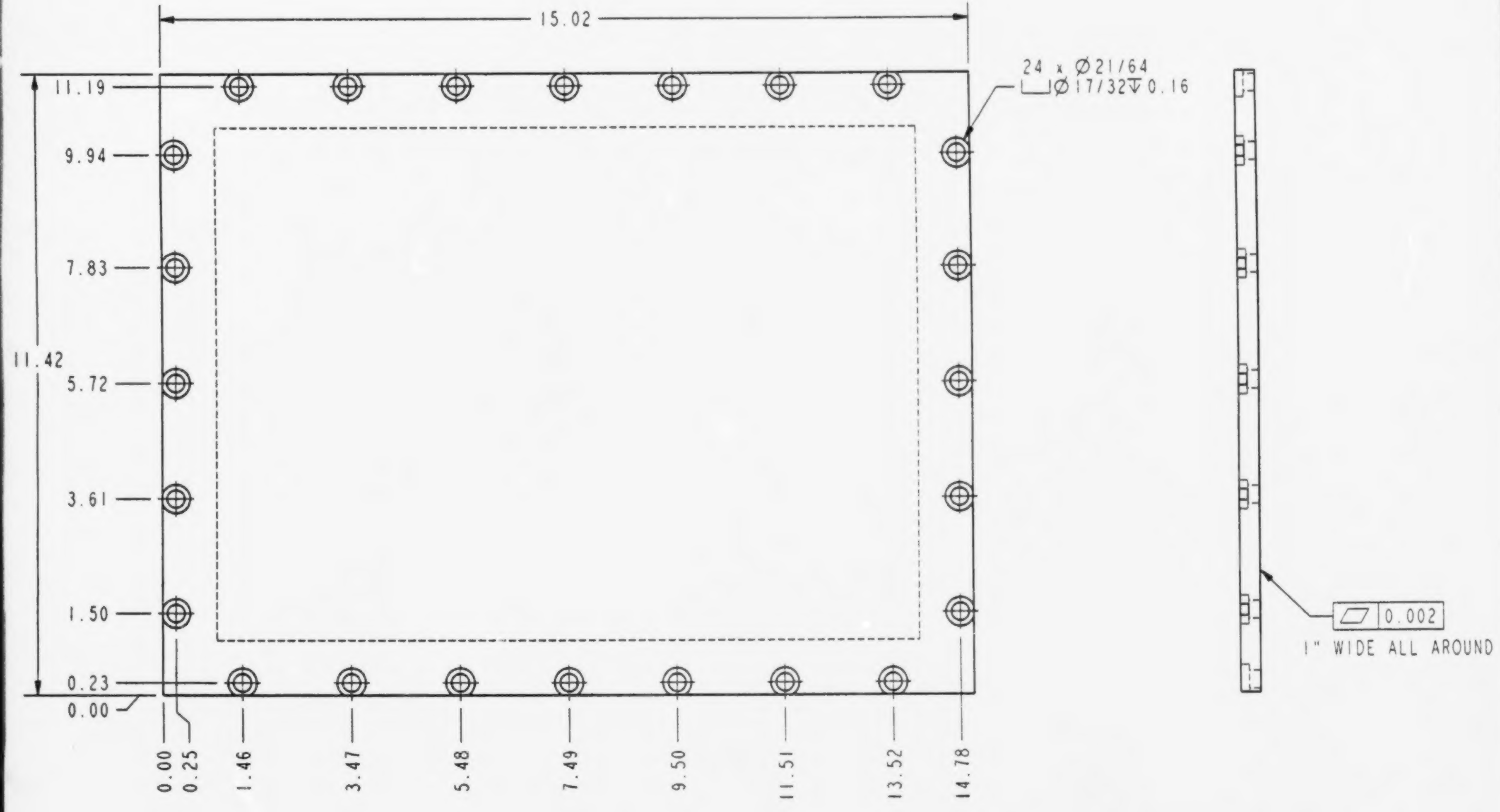
RIGHT HOUSING : UPPER COVER		
Designed: P. Gagnon	Verified: P.A.	
Drawn: L. Simard	Approved: G.G	
Sheet 1 of 1	Software: Pro/E 2000i	Size A
09-Sep-99	7737-MPC028A	

OITIER_PLAQUE_DESSUS_DROITE


15.02
11.42
11.19
9.94
7.83
5.72
3.61
1.50
0.23
0.00
0.00
0.25
1.46
3.47
5.48
7.49
9.50
11.51
13.52
14.78
24 x Ø21/64
⌴Ø17/32↧0.16
▱ 0.002
1" WIDE ALL AROUND

ORIGINAL

Scale: 3:8	Quantity: 1	Units: Inch
Material: Stainless steel 316L Pl. 3/8		
Surface treatment: Non[redacted]		

Tolerances after any surface treatment
x/x ± 1/32
x.x ± 0.010
x.xx ± 0.005
x.xxx ± 0.002
∠90° ± 1/4°
rough[redacted]erage: [redacted]

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369, Franquet St.
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Canada, G1P 4N8
Tel: (418) 657-7006
F[redacted]8) 65[redacted]

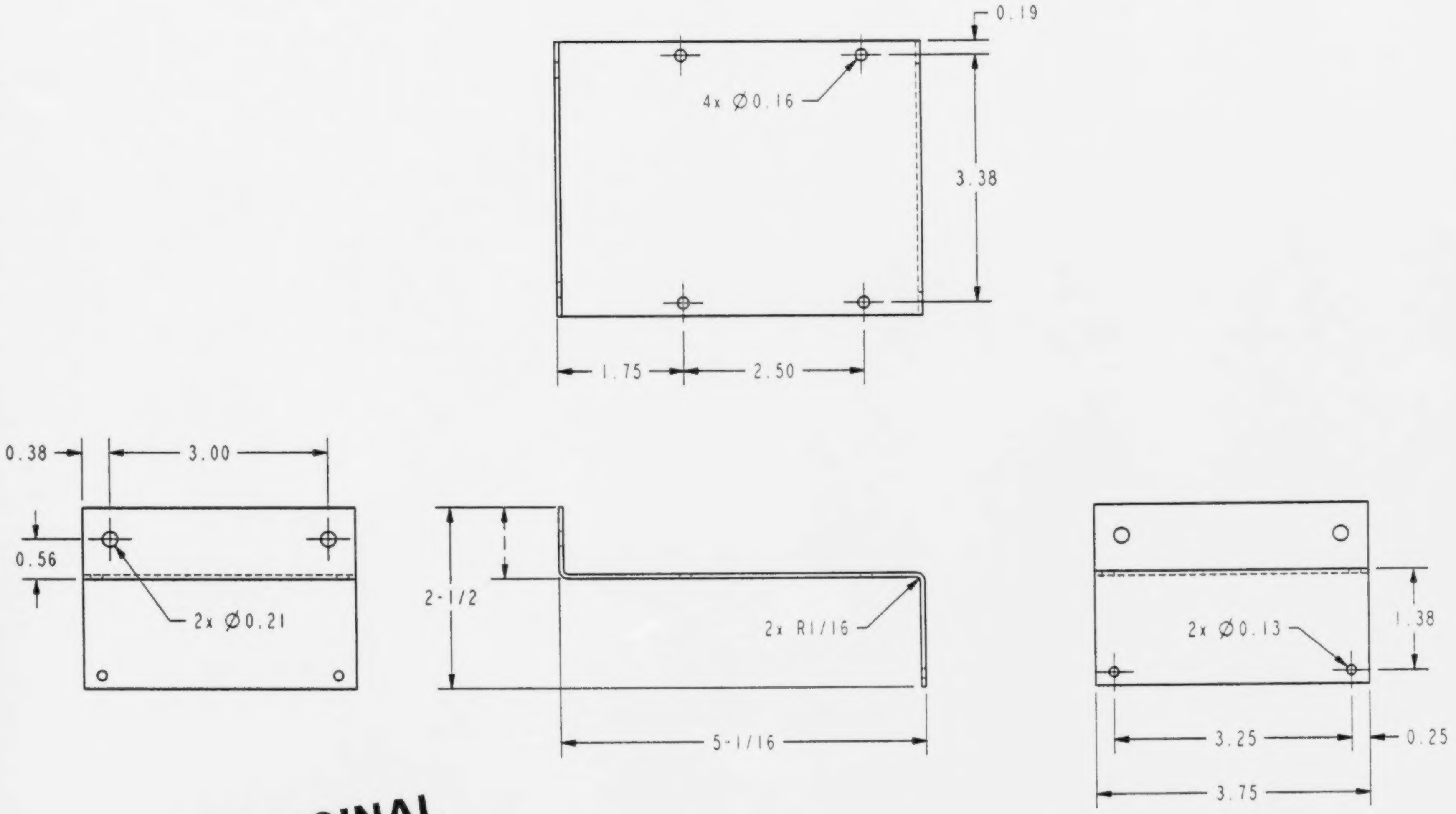
LEFT HOUSING : UPPER COVER

Designed: P. Gagnon	Verified: P.G.
Drawn: L. Simard	Approved: A.G.
Sheet 1 of 1	Software: Pro/E 2000i — Size A

[redacted]ep-[redacted] 7[redacted] MPC[redacted]A [redacted]

IER.PLAQUE_DESSUS_GAUCHE

evi[redacted] [redacted] D[redacted]tio[redacted] [redacted] Da[redacted] B[redacted]


0.19
4x Ø0.16
3.38
1.75
2.50
0.38
3.00
0.56
2x Ø0.21
2-1/2
2x R1/16
5-1/16
2x Ø0.13
1.38
3.25
0.25
3.75

ORIGINAL

Revision	Description	Date	By

Scale:	Quantity:	Units:
1:2	1	Inch

Material:
Aluminum 1100
Pl. 1/16
-

Surface treatment:
None

Tolerances after any surface treatment

x/x	± 1/64
x.x	± 0.010
x.xx	± 0.005
x.xxx	± 0.002
∠90°	± 1/4°

roughness average: 63√

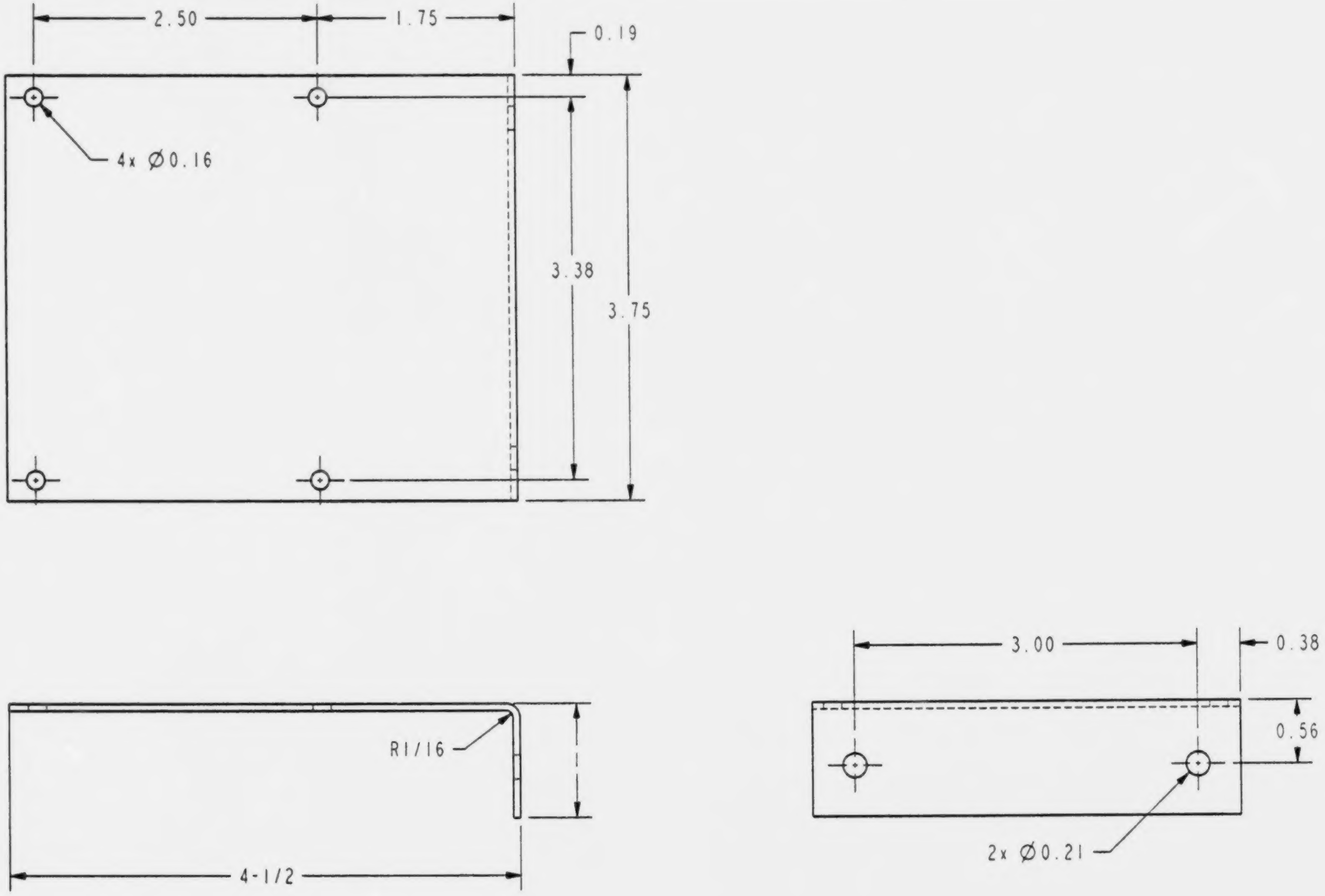
INO

369, Franquet St.
Sainte-Foy, Québec
Canada, G1P 4N8
Tel: (418) 657-7006
Fax: (418) 657-7009

SUPPORT FM VIDEO RECEIVER

Designed: S. Roy	Verified: P.L
Drawn: S. Roy	Approved: M.A.
Sheet 1 of 1	Software: Pro/E 2000i — Size A
09-Sep-99	7737-MPC030A

SUPPORT-FM-VIDEO-RECEIVER



ORIGINAL

Scale: 3:4	Quantity: 1	Units: Inch
Material: Aluminum 1100 Pl. 1/16 -		
Surface treatment: Non[redacted]		

Tolerances after any surface treatment
x/x ± 1/64
x.x ± 0.010
x.xx ± 0.005
x.xxx ± 0.002
∠90° ± 1/4°
roughness average:

INO

369, Franquet St.
Sainte-Foy, Québec
Canada, G1P 4N8
Tel: (418) 657-7006
Fa[redacted] (418) 657-[redacted]

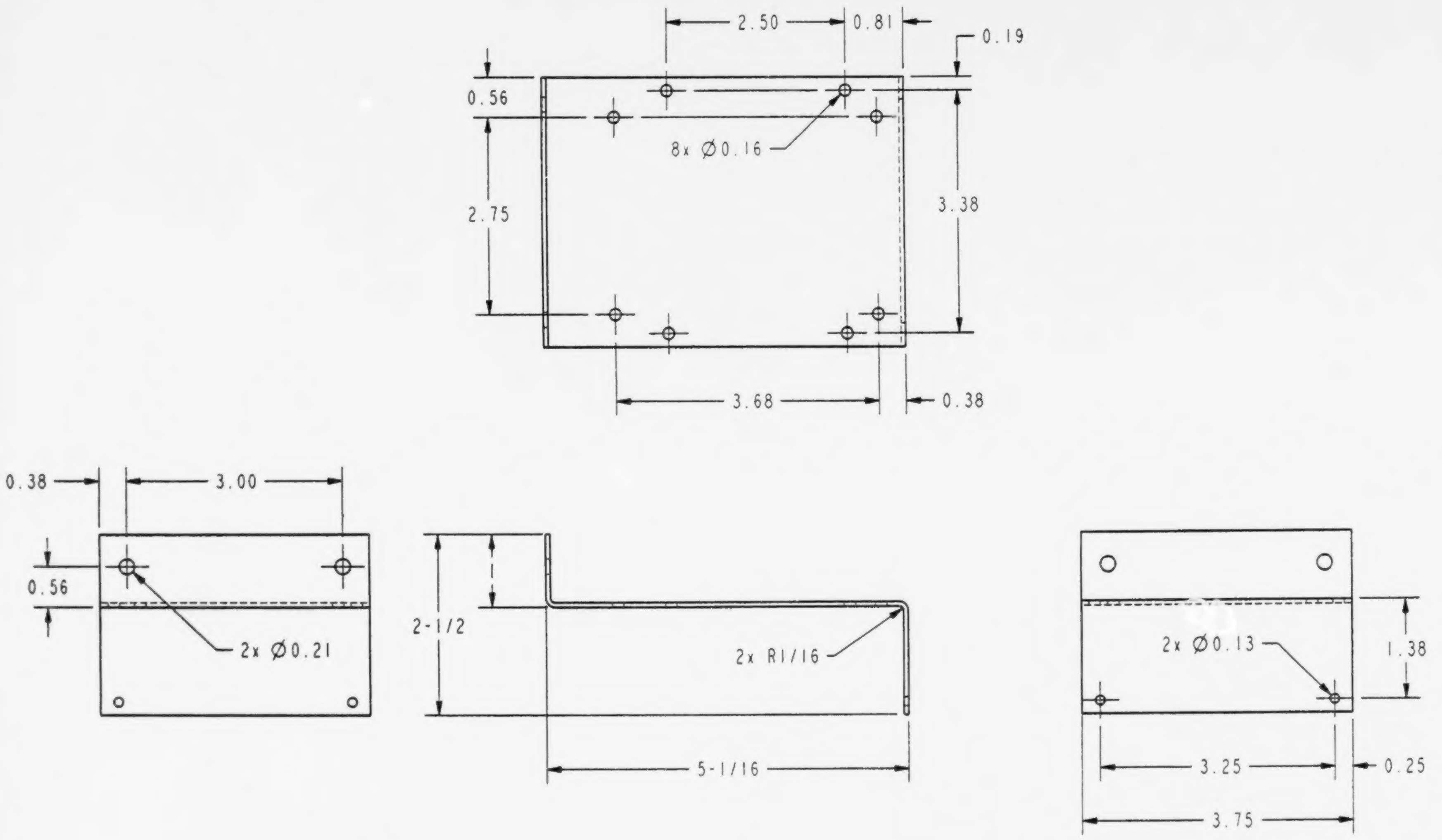
SUPPORT #2 FM VIDEO RECEIVER

Designed: S. Roy	Verified: P.J.
Drawn: S. Roy	Approved: M.A.
Sheet 1 of 1	Software: Pro/E 2000i
	Size A

:vi[redacted] [redacted] D[redacted]tio[redacted] [redacted] Da[redacted] B[redacted]

[redacted]ep-[redacted] 7[redacted]MPC[redacted]A [redacted]

ORT2-FM-VIDEO-RECEIVER


2.50
0.81
0.19
0.56
8x Ø0.16
2.75
3.38
3.68
0.38
0.38
3.00
0.56
2x Ø0.21
2-1/2
2x R1/16
5-1/16
2x Ø0.13
1.38
3.25
0.25
3.75

ORIGINAL

Scale: 1:2	Quantity: 1	Units: Inch
Material: Aluminum 1100 Pl. 1/16 -		
Surface treatment: None		

Tolerances after any surface treatment
x/x ± 1/64
x.x ± 0.010
x.xx ± 0.005
x.xxx ± 0.002
∠90° ± 1/4°
roughness average: 63√

INO

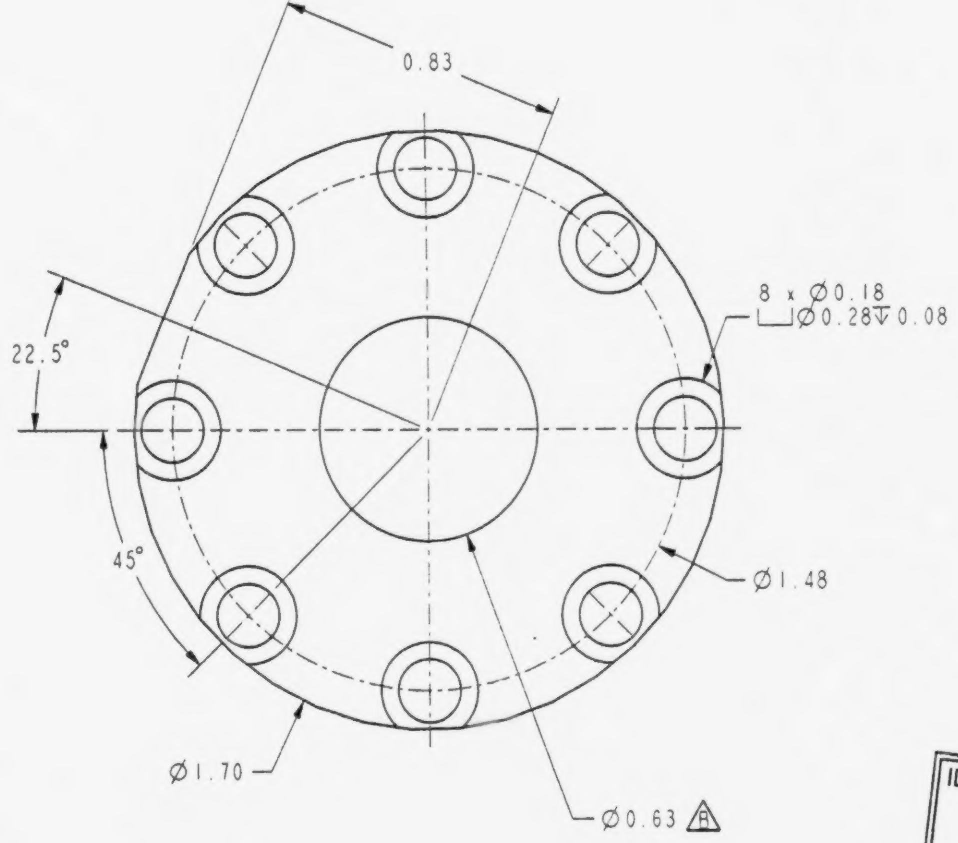
369, Franquet St.
Sainte-Foy, Québec
Canada, G1P 4N8
Tel: (418) 657-7006
Fax: (418) 657-7009

SUPPORT #3 FM VIDEO RECEIVER

Designed: S. Roy	Verified: P.D.
Drawn: S. Roy	Approved: M.A.
Sheet 1 of 1	Software: Pro/E 2000i — Size A
09-Sep-99	7737-MPC032A

evision	Description	Date	By

SUPPORT3-FM-VIDEO-RECEIVER



IDT-034
ORIGINAL

B	DIAMETER MODIFIED	13/04/00	L.S.
vis [redacted]	De[redacted]tio[redacted]	Da[redacted]	B[redacted]

Scale: 2:1
Quantity: 3
Units: Inch
Material:
Stainless steel 316L
Pl. 1/4
-
Surface treatment:
None [redacted]

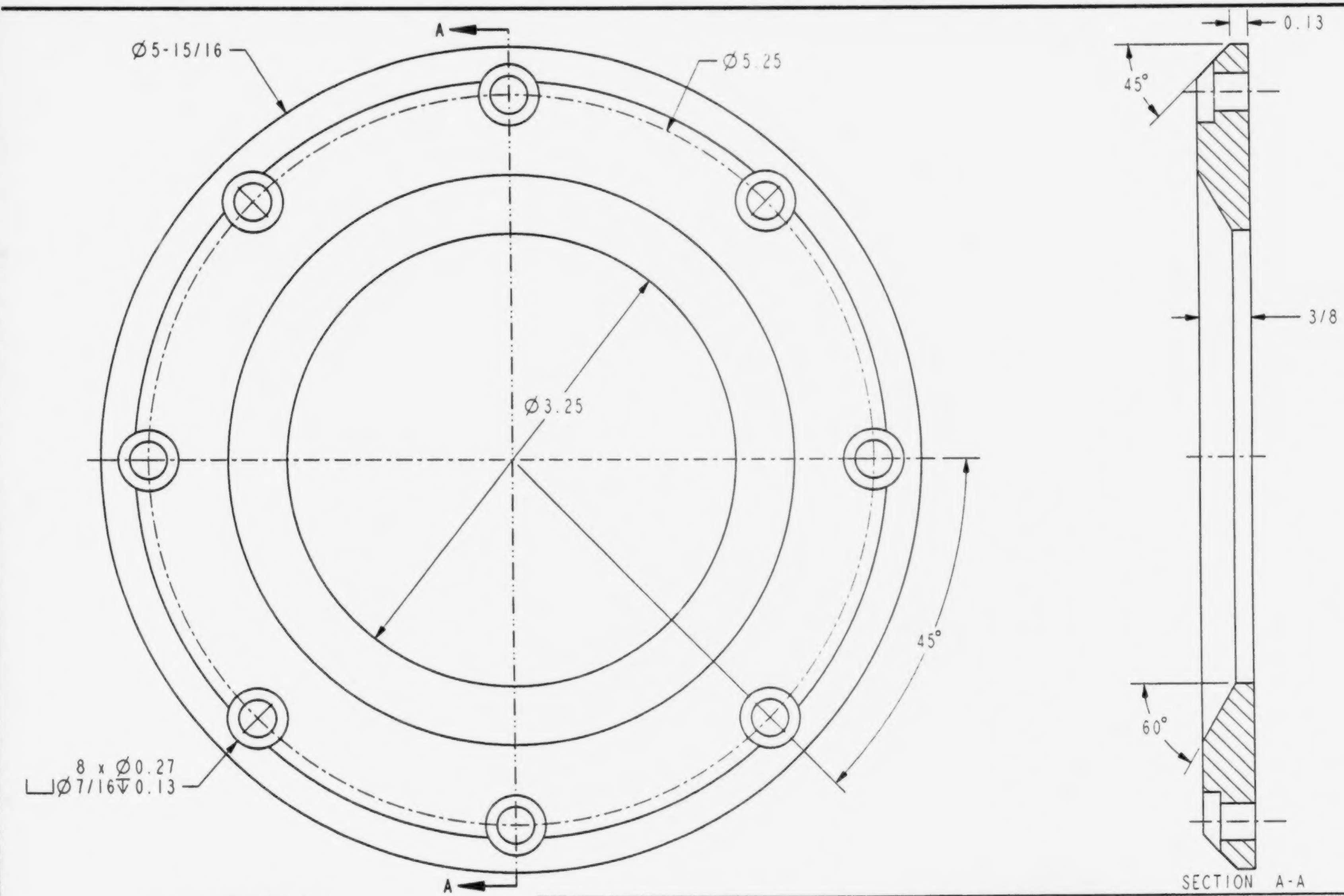
Tolerances after any surface treatment
x/x ± 1/32
x.x ± 0.010
x.xx ± 0.005
x.xxx ± 0.002
∠90° ± 1/4°
roughness average: [redacted]

INO
369, Franquet St.
Sainte-Foy, Quebec
Canada, G1P 4N8
Tel: (418) 657-7006
Fa[redacted] (418) 657-7009

EMISSION WINDOW : RING

Designed: P. Gagnon
Verified:
Drawn: L. Simard
Approved:
Sheet 1 of 1
Software: Pro/E 2000i
Size A
[redacted] ep-9[redacted] 7[redacted] MPC[redacted] B [redacted]

DE.FENETRE.EMISSION


Ø5-15/16
A
Ø5.25
Ø3.25
45°
8 x Ø0.27
⌴Ø7/16↧0.13
A
0.13
45°
3/8
60°
SECTION A-A

ORIGINAL

Scale:	Quantity:	Units:
1:1	3	Inch

Material:
Stainless steel 316L
-
-

Surface treatment:
None

Tolerances after any surface treatment
x/x ± 1/32
x.x ± 0.010
x.xx ± 0.005
x.xxx ± 0.002
∠90° ± 1/4°
roughness average: 63√

INO
369, Franquet St.
Sainte-Foy, Québec
Canada, G1P 4N8
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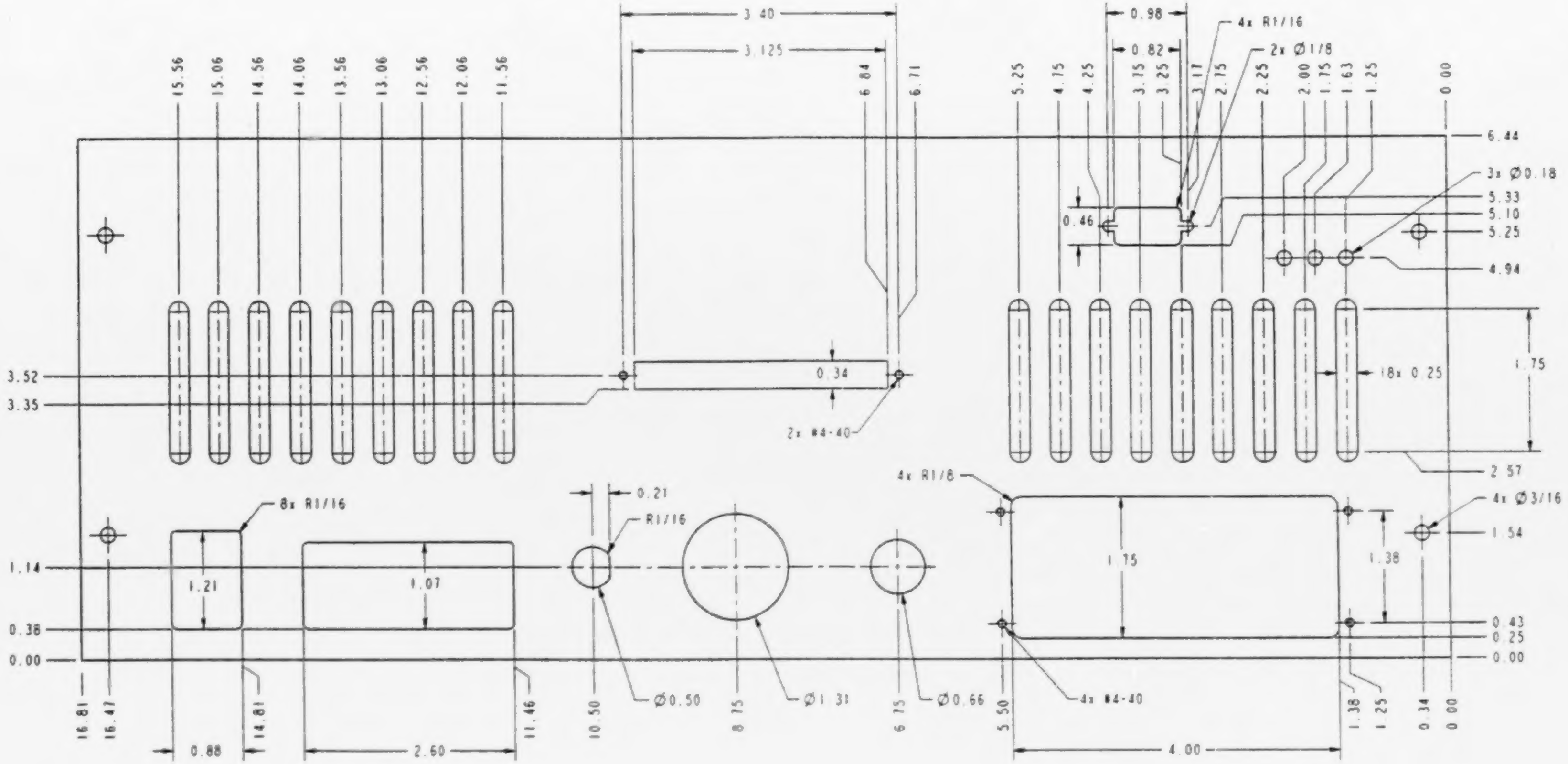
Fax: (418) 657-7009

RECEPTION WINDOW : RING		
Designed: P. Gagnon	Verified: P.L	
Drawn: L. Simard	Approved: G.W	
Sheet 1 of 1	Software: Pro/E 2000i	Size A
10-Sep-99	7737-MPC034A	

BAGUE_FENETRE_RECEPTION

vision	Description	Date	By


3.40
3.125
0.98
0.82
4x R1/16
2x Ø1/8
15.56
15.06
14.56
14.06
13.56
13.06
12.56
12.06
11.56
6.84
6.71
5.25
4.75
4.25
3.75
3.25
3.17
2.75
2.25
2.00
1.75
1.63
1.25
0.00
6.44
3x Ø0.18
5.33
5.10
5.25
4.94
0.46
1.75
18x 0.25
3.52
3.35
0.34
2x #4-40
2.57
4x R1/8
4x Ø3/16
1.54
8x R1/16
0.21
R1/16
1.14
1.21
1.07
1.75
1.38
0.38
0.00
0.43
0.25
0.00
16.81
16.47
14.81
11.46
10.50
Ø0.50
8.75
Ø1.31
6.75
Ø0.66
5.50
4x #4-40
1.38
1.25
0.34
0.00
0.88
2.60
4.00

ORIGINAL

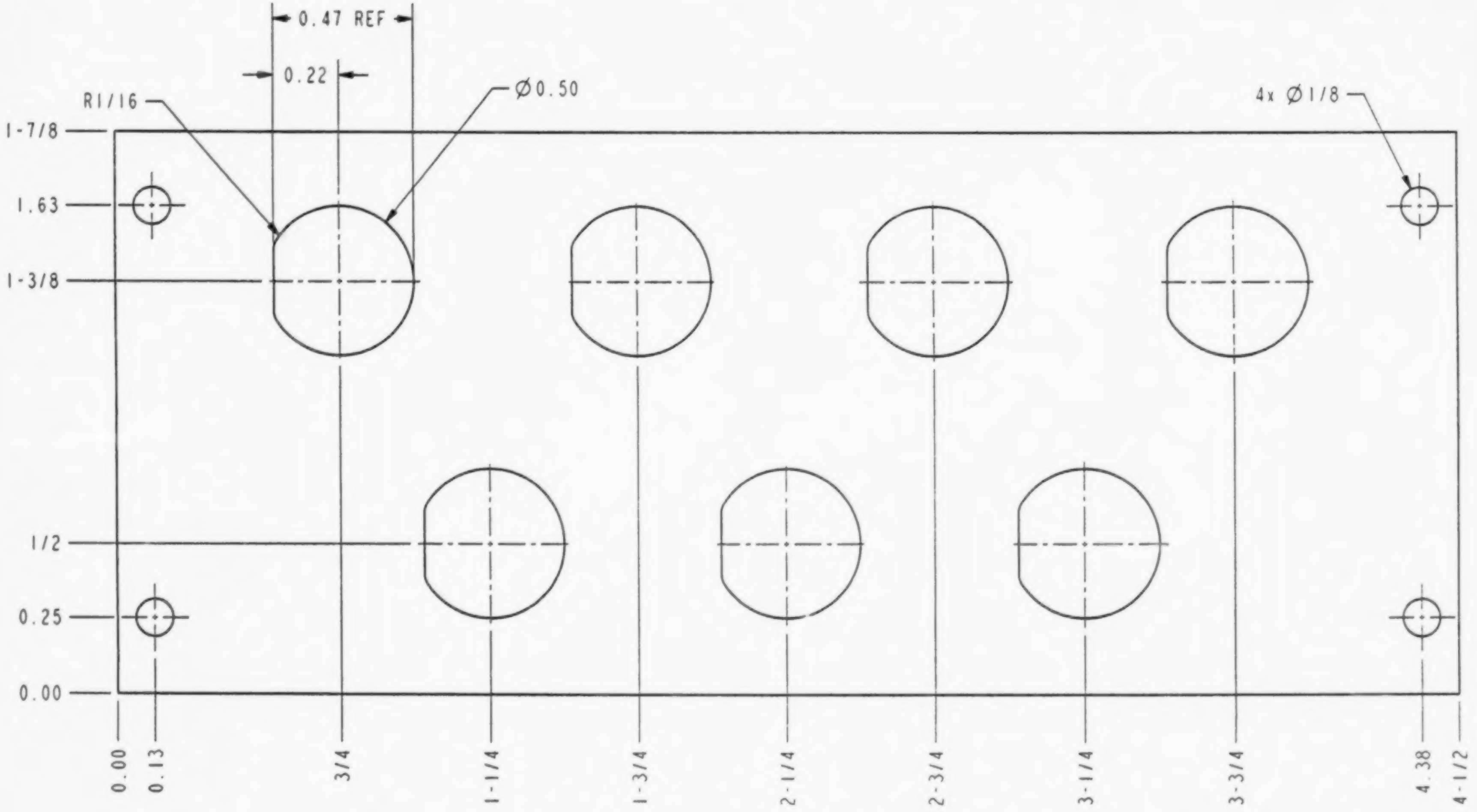
Revision	Description	Date	By

Scale: 3:4
Quantity: 1
Units: inch
Material:
Aluminum 6061-T6
Pl. 1/8
-
Surface treatment:
natural anodizing

Tolerances after any surface treatment
x/x ± 1/32
x.x ± 0.010
x.xx ± 0.005
x.xxx ± 0.002
∠90° ± 1/4°
roughness average 63/

INO
369, Franquet St.
Sainte-Foy, Québec
Canada, G1P 4N8
Tel.: (418) 657-7006
Fax: (418) 657-7009

REAR PANEL
Designed: S. Roy
Verified: B.B.
Drawn: S. Roy
Approved: B.B.
Sheet 1 of 1
Software: Pro/E 2000i
Size: B
13-Sep-99
7737-MPC035A


0.47 REF
0.22
R1/16
Ø0.50
4x Ø1/8
1-7/8
1.63
1-3/8
1/2
0.25
0.00
0.00
0.13
3/4
1-1/4
1-3/4
2-1/4
2-3/4
3-1/4
3-3/4
4.38
4-1/2

ORIGINAL

evision	Description	Date	By

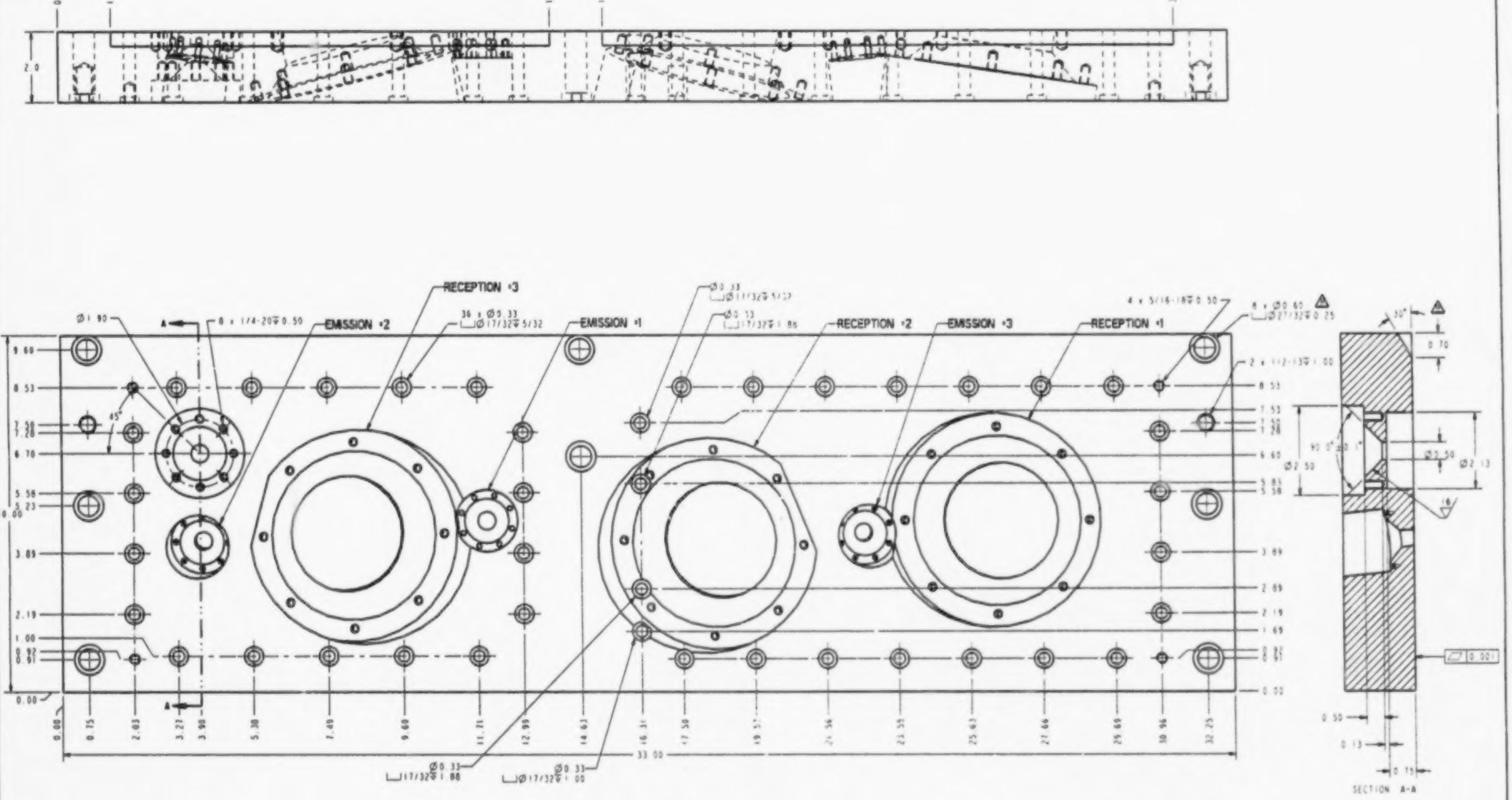
Scale: 2:1
Quantity: 1
Units: Inch
Material:
Black delrin
Pl. 1/8
-
Surface treatment:
None

Tolerances after any surface treatment
x/x ± 1/32
x.x ± 0.010
x.xx ± 0.005
x.xxx ± 0.002
∠90° ± 1/4°
roughness average: 63√

INO
369, Franquet St
Sainte-Foy, Québec
Canada, G1P 4N8
Tel: (418) 657-7006
Fax: (418) 657-7009

BNC PLATE
Designed: S. Roy
Verified: AB
Drawn: S. Roy
Approved: M.A
Sheet 1 of 1
Software: Pro/E 2000i
Size A
13-Sep-99
7737-MPC036A

PLAQUE-BNC


0.00
1.5
13.9
15.4
31.5
2.0
RECEPTION #3
EMISSION #2
EMISSION #1
RECEPTION #2
EMISSION #3
RECEPTION #1
Ø1.90
8 x 1/4-20 ▽ 0.50
36 x Ø0.33
⌴Ø17/32 ▽ 5/32
Ø0.33
⌴Ø17/32 ▽ 5/32
Ø0.33
⌴17/32 ▽ 1.86
4 x 5/16-18 ▽ 0.50
8 x Ø0.60
⌴Ø27/32 ▽ 0.25
2 x 1/2-13 ▽ 1.00
Ø0.33
⌴17/32 ▽ 1.88
Ø0.33
⌴Ø17/32 ▽ 1.00
A
45°
9.60
8.53
7.50
7.28
6.70
5.58
5.23
10.00
3.89
2.19
1.00
0.92
0.81
0.00
0.75
2.03
3.27
3.90
5.30
7.49
9.60
11.71
12.99
14.63
16.31
17.50
19.57
21.56
23.55
25.63
27.66
29.69
30.96
32.25
33.00
7.53
6.60
5.83
2.89
1.69
30°
0.70
90.0° ±0.1°
Ø2.50
Ø2.50
Ø2.13
16
0.001
0.50
0.13
0.75
SECTION A-A

IDT-044
DUPLICATA

NOTE : REMOVE ALL SHARP EDGES.

Scale	Quantity	Units
1:2	1	Inch

Material
Stainless steel 316L

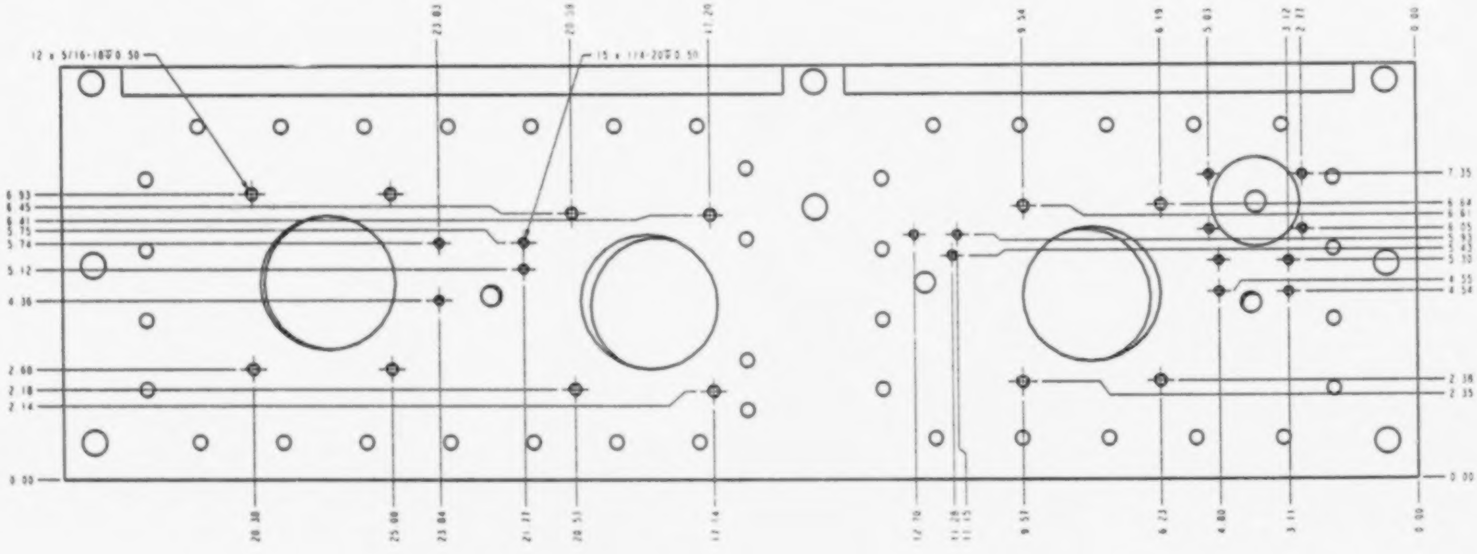
Surface treatment
None

Tolerance after any surface treatment
x/x ± 1/32
x.x ± 0.010
x.xx ± 0.005
x.xxx ± 0.002
∠ ± 1/2°
[illegible]

INO
309, Franquet St
Sainte-Foy, Quebec
Canada, G1P 4N8
Tel (418) 657 7006
Fax (418) 657 7009

WINDOW PLATE, HOUSING
Designed P. Gagnon
Verified
Drawn L. Simard
Approved
Sheet 1 of 6
Software [illegible] 2000i
Size C
13-Sep-99
7737-HPC0370

B	HOLES AND CHAMFER MODIFIED	14/04/00	L.S.
Revision	Description	Date	By


12 x 5/16-18↧0.50
15 x 1/4-20↧0.50
23.83
20.39
17.20
9.54
6.19
5.03
3.12
2.22
0.00
6.93
6.45
6.41
5.75
5.74
5.12
4.36
2.60
2.18
2.14
0.00
7.35
6.64
6.61
6.05
5.93
5.43
5.30
4.55
4.54
2.38
2.35
0.00
28.38
25.00
23.84
21.77
20.53
17.14
12.70
11.28
11.15
9.57
6.23
4.80
3.11
0.00

IDT-044
DUPLICATA

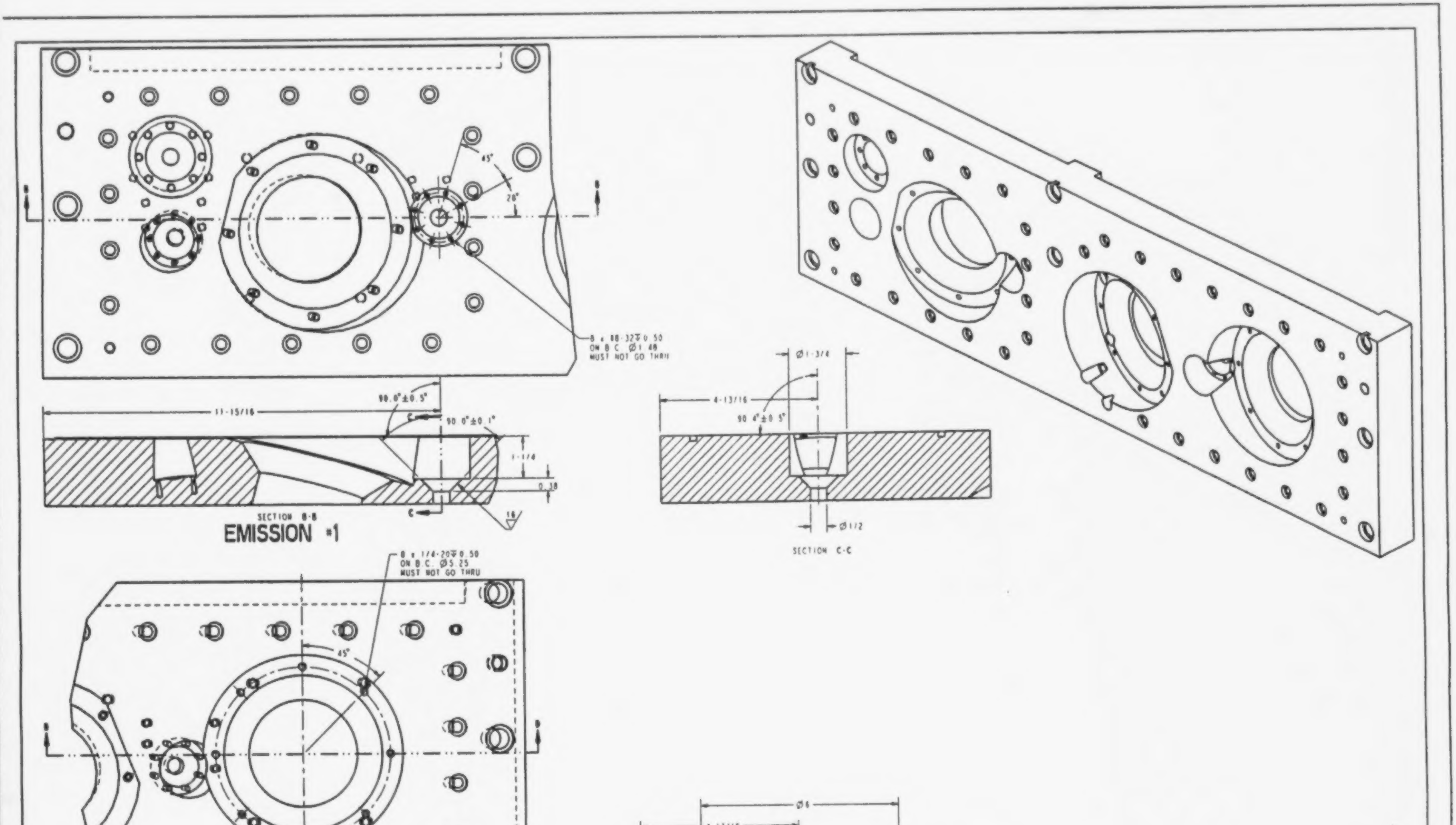
B	REVIEW ON SHEET #1, 3, 4	04/10/99	L.S.
Revision	Description	Date	By

Scale 1:2
Quantity 1
Units Inch
Material
Surface treatment

Tolerance after any surface treatment
x/x ± 1/32
x.x ± 0.010
x.xx ± 0.005
x.xxx ± 0.002
∠ ± 1/2°
roughness average

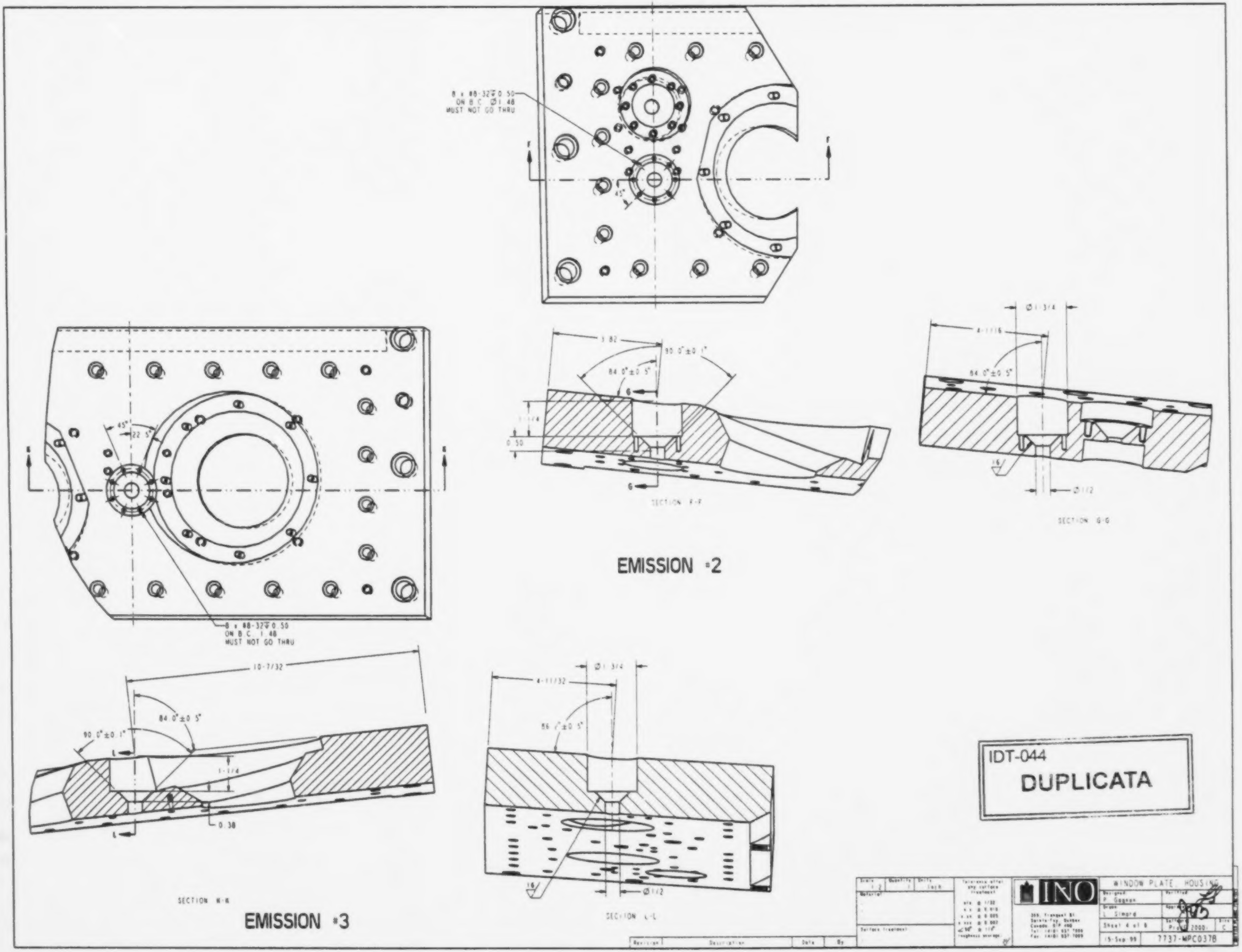
INO
385, Franquet St.
Sainte-Foy, Québec
Canada, G1P 4N8
Tel: (418) 657-7006
Fax: (418) 657-7009

WINDOW PLATE, HOUSING
Designed P. Gagnon
Verified
Drawn L. Simard
Approved
Sheet 2 of 6
Date 2000
Size C
13-Sep-99
7737-MPC0378


8 x #8-32 ⌄ 0.50
ON B.C. Ø1.48
MUST NOT GO THRU
45°
20°
11-15/16
90.0°±0.5°
90.0°±0.1°
1-1/4
0.38
16
SECTION B-B
EMISSION #1
Ø1-3/4
4-13/16
90.4°±0.5°
Ø1/2
SECTION C-C
8 x 1/4-20 ⌄ 0.50
ON B.C. Ø5.25
MUST NOT GO THRU
45°
6-3/4
98.4°±0.5°
90.0°±0.1°
7/8
0.75
16
SECTION D-D
RECEPTION #1
Ø6
4-13/16
90.4°±0.5°
Ø3-1/4
SECTION E-E
Scale 1:2
Quantity 1
Units Inch
Material
Surface treatment
Tolerance after any surface treatment
INO
WINDOW PLATE, HOUSING
Designed P. Gagnon
Drawn L. Simard
Sheet 3 of 8
Size C
15-Sep-99
7737-MPC037B
Revision
Description
Date
By

IDT-044

DUPLICATA


8 x #8-32 ⧩ 0.50
ON B.C. Ø1.48
MUST NOT GO THRU
F
F
45°
3.82
90.0° ± 0.1°
84.0° ± 0.5°
G
G
1-1/4
0.50
SECTION F-F
Ø1-3/4
4-1/16
84.0° ± 0.5°
16
Ø1/2
SECTION G-G
EMISSION #2
K
K
45°
22.5°
8 x #8-32 ⧩ 0.50
ON B.C. 1.48
MUST NOT GO THRU
10-7/32
84.0° ± 0.5°
90.0° ± 0.1°
L
L
1-1/4
0.38
SECTION K-K
EMISSION #3
Ø1-3/4
4-11/32
86.0° ± 0.5°
16
Ø1/2
SECTION L-L

IDT-044
DUPLICATA

Scale	Quantity	Units
1:2	1	Inch

Material

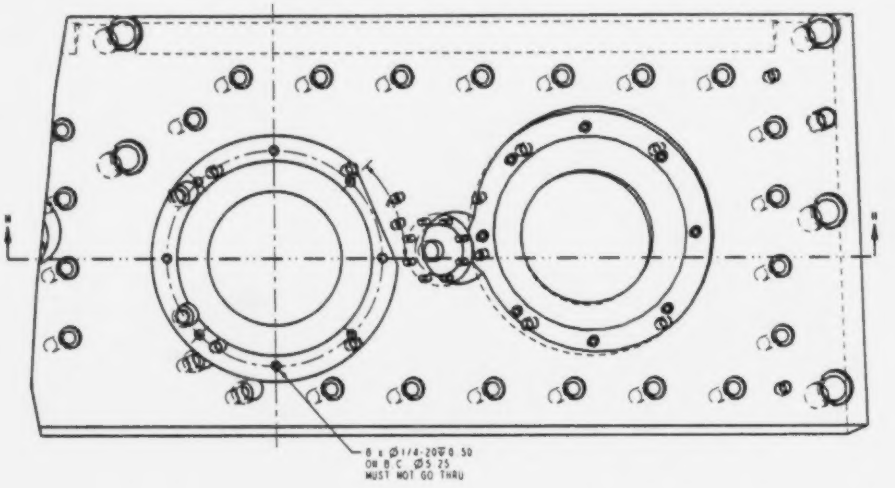
Surface treatment

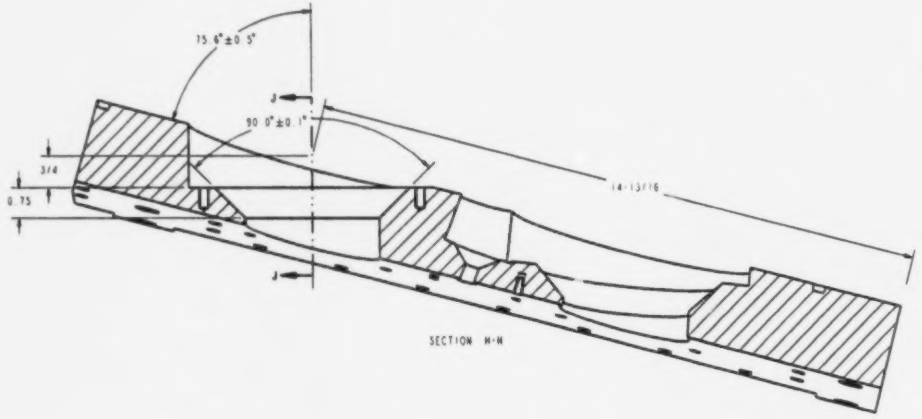
Tolerance after any surface treatment
x/x ± 1/32
x.x ± 0.010
x.xx ± 0.005
x.xxx ± 0.002
∠ xx° ± 1/2°
roughness average

INO
300, Franquet St.
Sainte-Foy, Quebec
Canada G1P 4N8
Tel: (418) 657-7006
Fax: (418) 657-7009

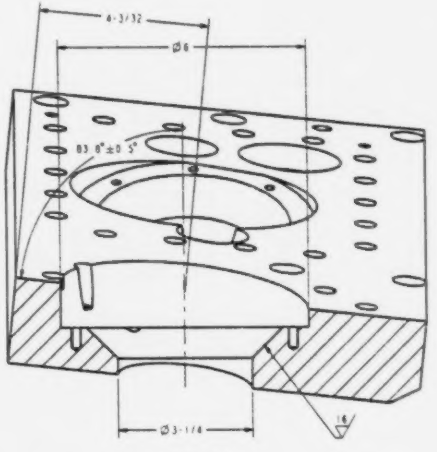
WINDOW PLATE, HOUSING
Designed: P. Gagnon
Verified:
Drawn: L. Simard
Approved:
Sheet 4 of 8
Project: 2000-
Size: C
15-Sep-99
7737-MPC0378

Revision	Description	Date	By


H
H
8 x Ø1/4-20⊽0.50
ON B.C. Ø5.25
MUST NOT GO THRU


75.6°±0.5°
90.0°±0.1°
J
J
3/4
0.75
14-13/16

SECTION H-H


4-3/32
Ø6
83.8°±0.5°
Ø3-1/4
16

SECTION J-J

RECEPTION *2

IDT-044
DUPLICATA

Revision	Description	Date	By

Scale	Quantity	Units
1:2	1	Inch

Material
-
-
-

Surface treatment
-

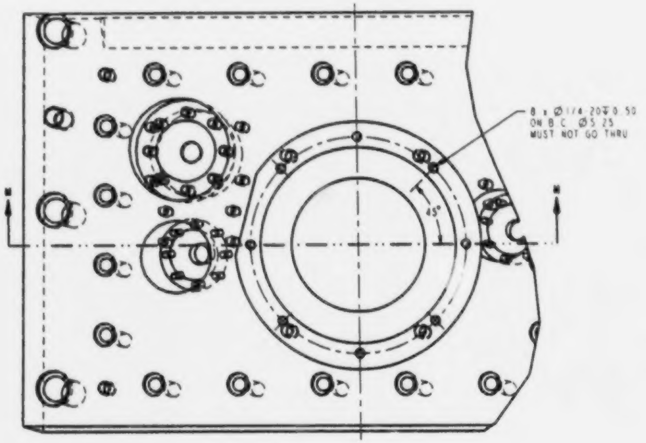
Tolerance after any surface treatment
x/x ± 1/30
x.x ± 0.010
x.xx ± 0.005
x.xxx ± 0.002
∠ xx° ± 1/2°
roughness µin(µm)

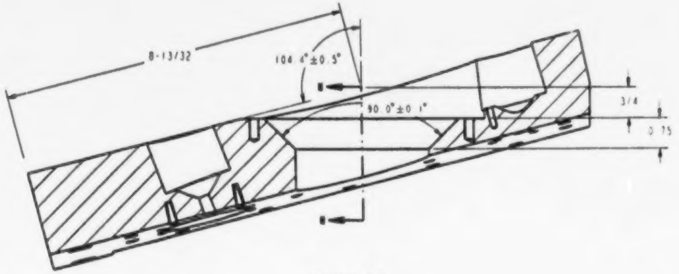
INO
369, Franquet St
Sainte-Foy, Quebec
Canada, G1P 4N8
Tel (418) 657 7006
Fax (418) 657 7009

WINDOW PLATE, HOUSING

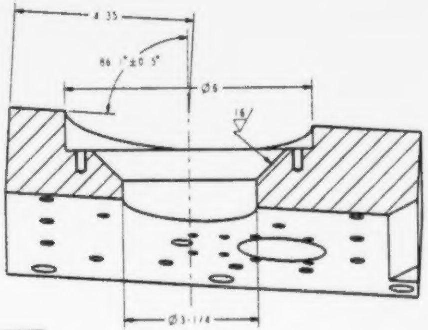
Designed P. Gagnon	Verified
Drawn L. Simard	Approved
Sheet 5 of 6	Software Pro/E 2000i
15-Sep-99	7737-MPC0378

Size C


8 x Ø1/4 20 ↧ 0.50
ON B.C. Ø5.25
MUST NOT GO THRU
45°
M
M


8-13/32
104.4°±0.5°
M
90.0°±0.1°
3/4
0.75
M

SECTION M-M


4.35
86.1°±0.5°
Ø6
16
Ø3-1/4

SECTION N-N

RECEPTION #3

IDT-044
DUPLICATA

Revision	Description	Date	By

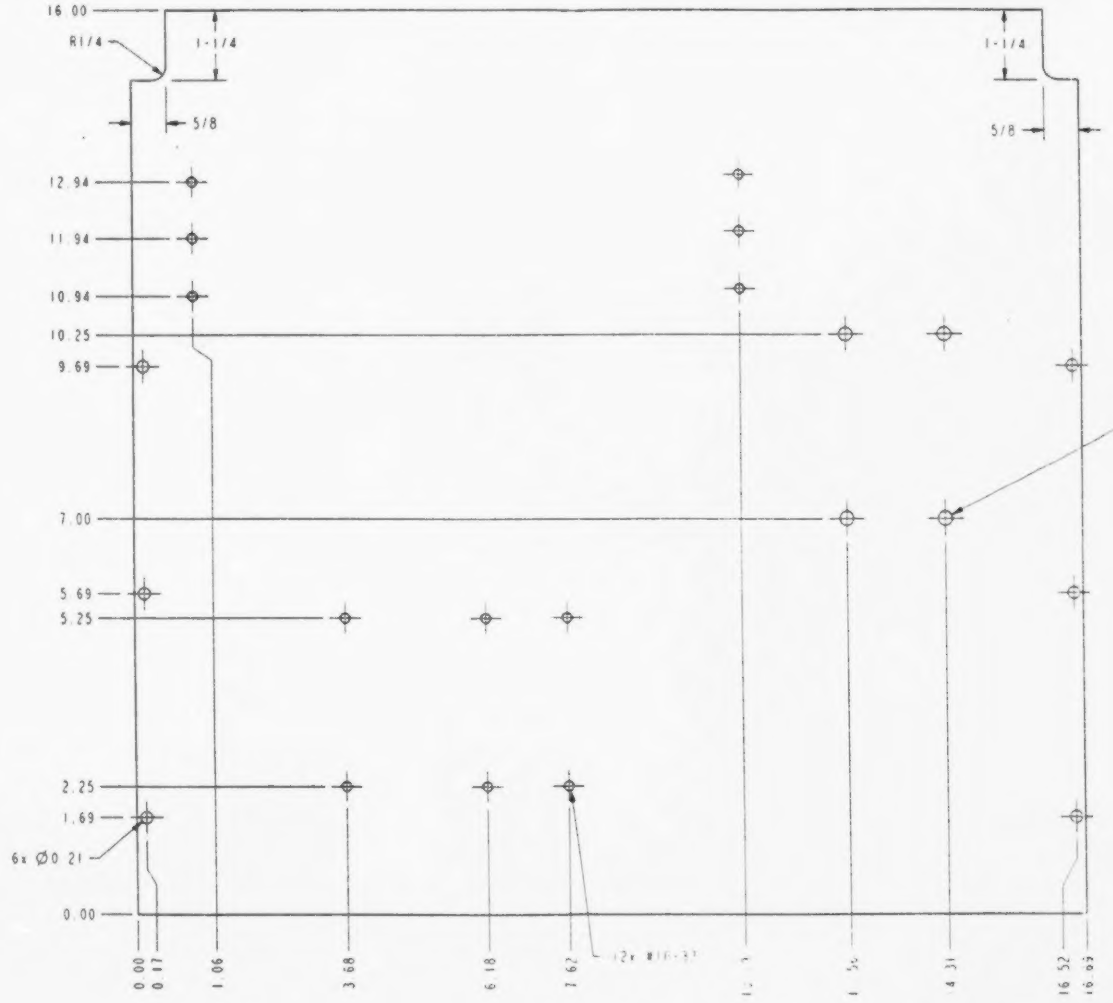
Scale 1:2	Quantity 1	Units Inch
Material		
Surface treatment		

Tolerance after any surface treatment
x/x ± 1/32
x.x ± 0.010
x.xx ± 0.005
x.xxx ± 0.002
∠90° ± 1/2°
roughness average

INO
369, Franquet St
Sainte-Foy, Quebec
Canada, G1P 4N8
Tel: (418) 657 7006
Fax: (418) 657 7009

WINDOW PLATE, HOUSING

Designed P. Gagnon	Verified	
Drawn L. Simard	Approved	
Sheet 6 of 6	Software Pro/E 2000i	Size C
15-Sep-99	7737-MPC0378	


16.00
R1/4
1-1/4
5/8
1-1/4
5/8
12.94
11.94
10.94
10.25
9.69
7.00
5.69
5.25
2.25
1.69
6x Ø0.21
0.00
4x Ø0.25
0.00
0.17
1.06
3.68
6.18
7.62
12x #10-32
14.31
16.52
16.69

ORIGINAL

Scale	Quantity	Units
1:2	1	inch

Material
Aluminum 6061-T6
Pl. 1/4

Surface treatment
None

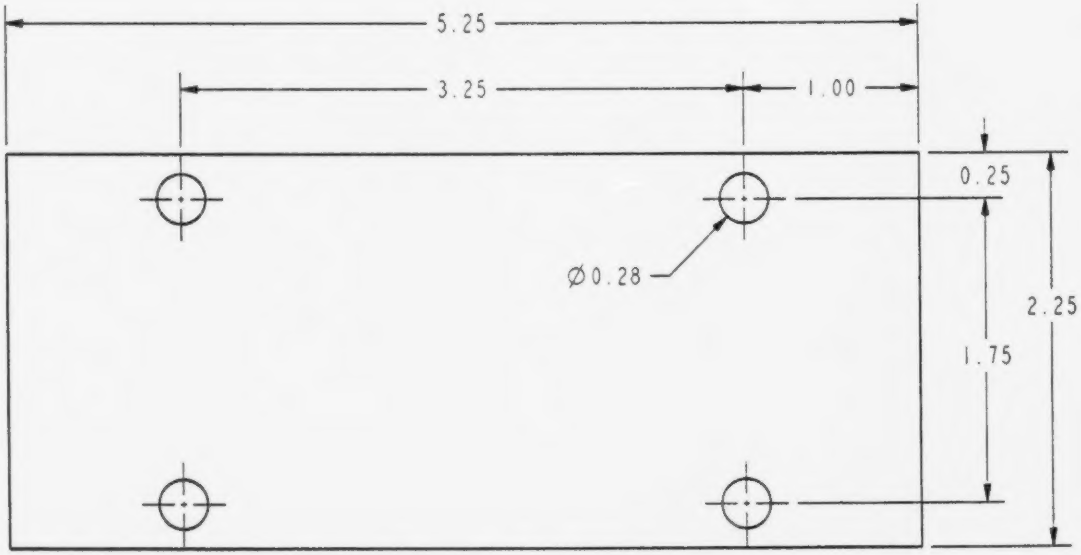
Tolerances after any surface treatment
x/x ± 1/32
x.x ± 0.010
x.xx ± 0.005
x.xxx ± 0.002
∠90° ± 1/4°
roughness average 63

Revision	Description	Date	By

INO
369, Franquet St
Sainte-Foy, Québec
Canada, G1P 4N8
Tel (418) 657-7006
Fax (418) 657-7009

BASE PLATE

Designed: S. Roy
Drawn: S. Roy
Verified: P.L.
Approved: P.L.
Sheet 1 of 1
Software: Pro/E 2000i
Size: B
15-Sep-99
7737-MPC038A



ORIGINAL

Scale: 1:1	Quantity: 1	Units: Inch

Material:
Aluminum 6061-T6
Pl. 1/8
-

Surface treatment:
None

Tolerances after any surface treatment
x/x ± 1/32
x.x ± 0.010
x.xx ± 0.005
x.xxx ± 0.002
∠90° ± 1/4°
roughness average: 63

INO

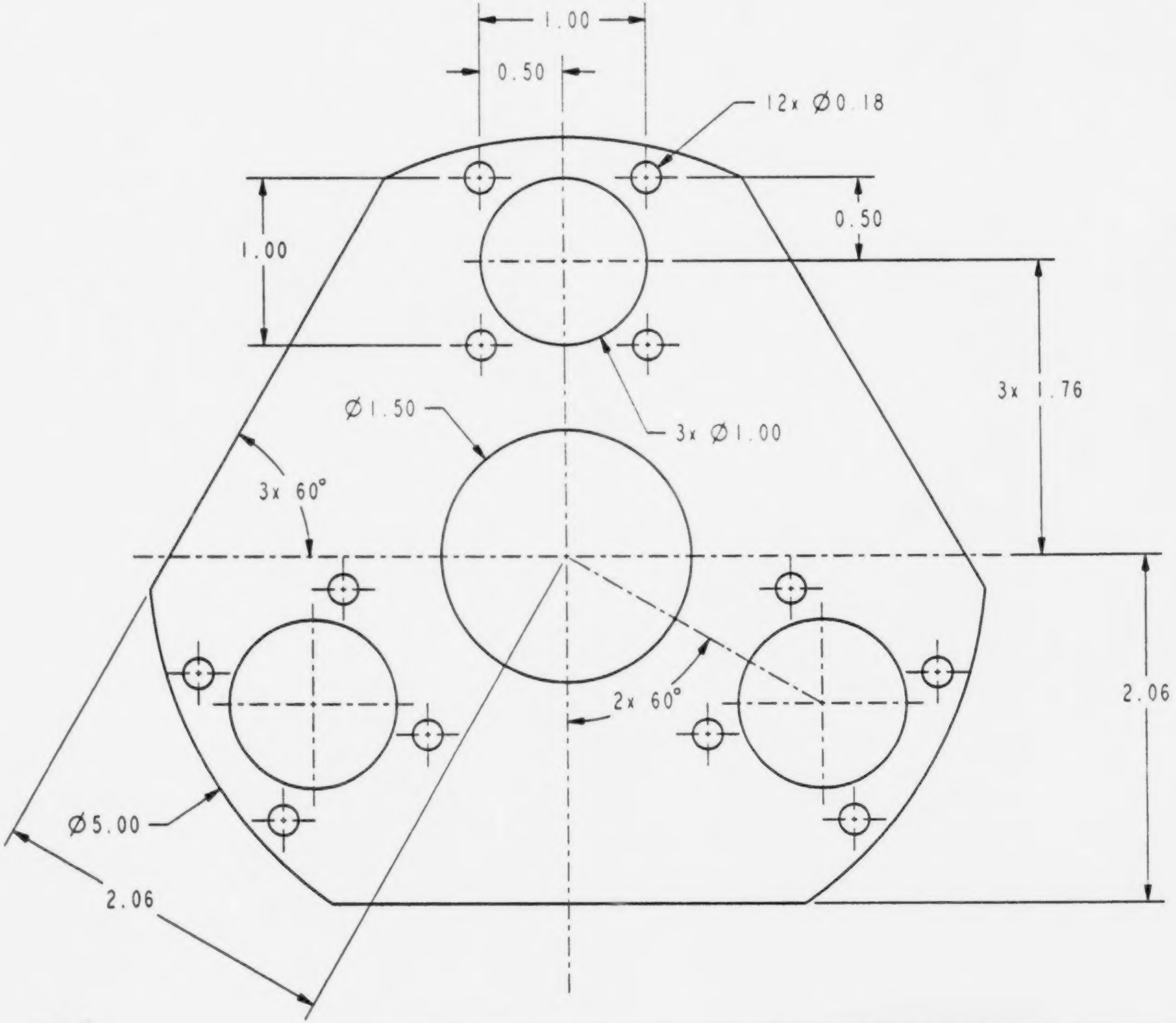
369, Franquet St.
Sainte-Foy, Québec
Canada, G1P 4N8
Tel: (418) 657-7006
Fax: (418) 657-7009

SUSPENSION PLATE

Designed: S. Roy
Verified:
Drawn: S. Roy
Approved:
Sheet 1 of 1
Software: Pro/E 2000i
Size A
15-Sep-99
7737-MPC039A

PLAQUE SUSPENSION

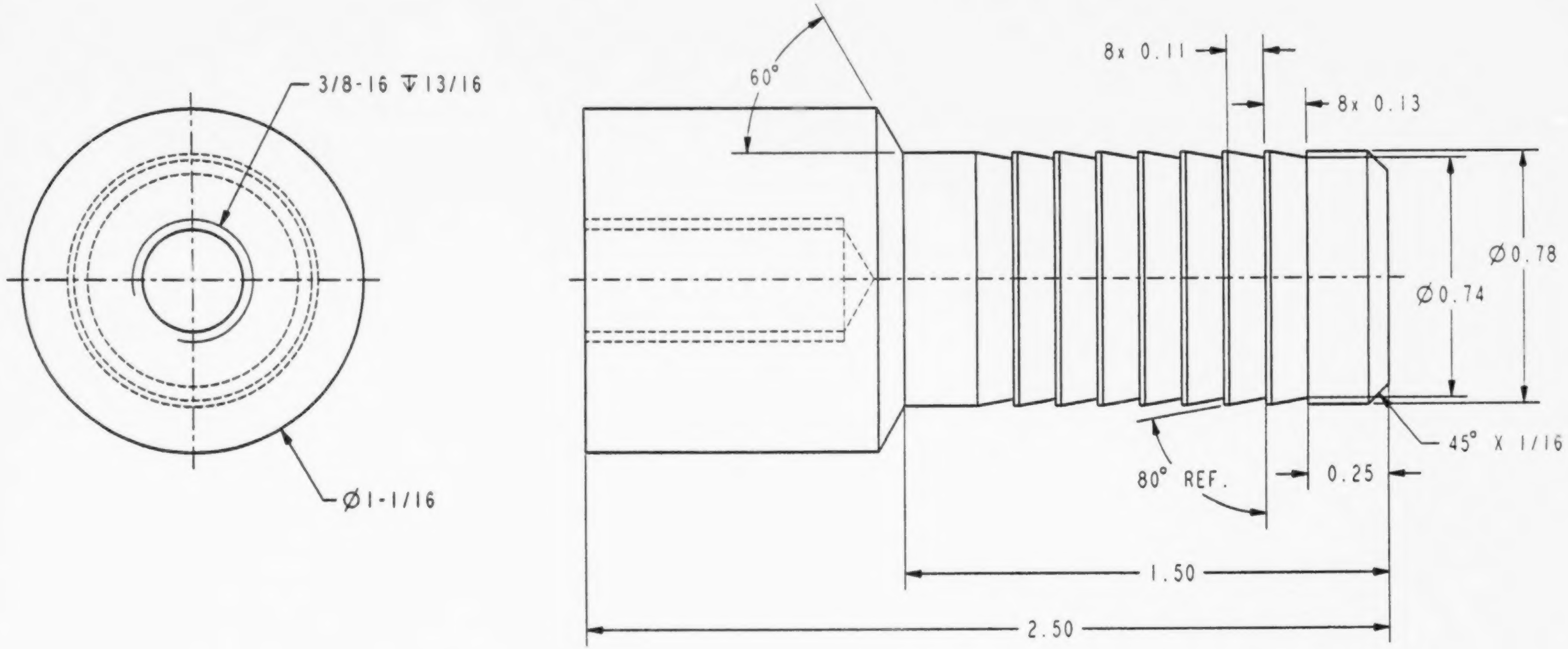
evision	Description	Date	By


1.00
0.50
12x Ø0.18
1.00
0.50
3x 1.76
Ø1.50
3x Ø1.00
3x 60°
2x 60°
2.06
Ø5.00
2.06

ORIGINAL

Scale: 1:1	Quantity: 1	Units: Inch	Tolerances after any surface treatment	INO	RENFORT	
Material: Aluminum 6061-T6 pl. 1/16 -			x/x ± 1/32 x.x ± 0.010 x.xx ± 0.005 x.xxx ± 0.002 ∠90° ± 1/4° roughness average:	369, Franquet St. Sainte-Foy, Québec Canada, G1P 4N8 Tel: (418) 657-7006 Fax: (418) 657-7009	Designed: S. Roy	Verified: P.L.
					Drawn: S. Roy	Approved: M.A.
Surface treatment: Non[redacted]					Sheet 1 of 1	Software: Pro/E 2000i — Size A
					Sep-[redacted]	7[redacted]-MP[redacted]A

evi[redacted] D[redacted]pti[redacted] D[redacted]


3/8-16 ↧13/16
Ø1-1/16
60°
8x 0.11
8x 0.13
Ø0.78
Ø0.74
45° X 1/16
80° REF.
0.25
1.50
2.50

ORIGINAL

Scale: 2:1	Quantity: 1	Units: Inch
Material: Stainless steel - -		
Surface treatment: None		

Tolerances after any surface treatment
x/x ± 1/32
x.x ± 0.010
x.xx ± 0.005
x.xxx ± 0.002
∠90° ± 1/4°
roughness average: 63√

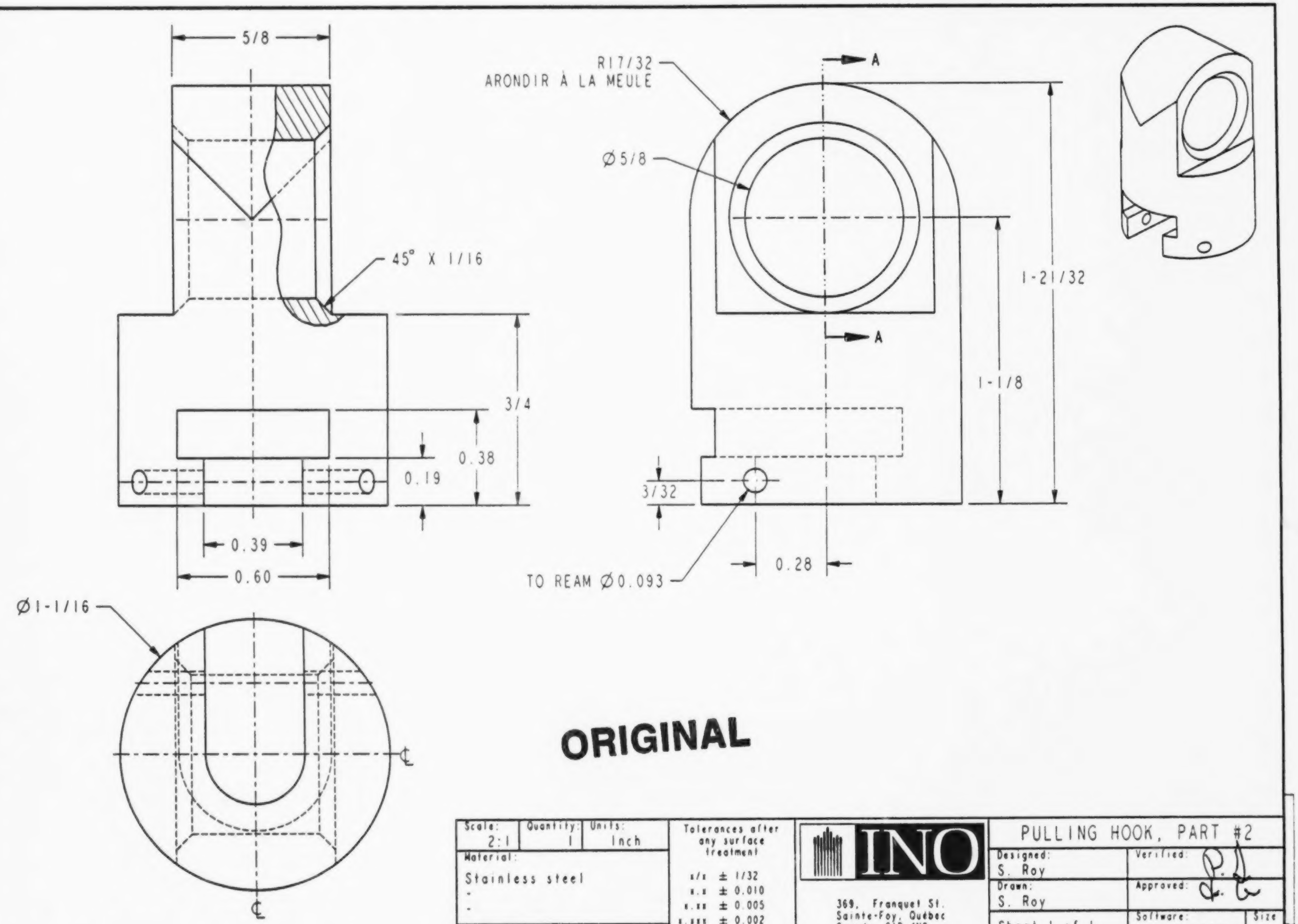
INO

369, Franquet St.
Sainte-Foy, Québec
Canada, G1P 4N8
Tel: (418) 657-7006
Fax: (418) 657-7009

PULLING HOOK, PART #1		
Designed: S. Roy	Verified:	
Drawn: S. Roy	Approved: a. lw-	
Sheet 1 of 1	Software: Pro/E 2000i	Size A
20-Sep-99	7737-MPC042A	

evision	Description	Date	By

CROCHET


5/8
R17/32
ARONDIR À LA MEULE
A
A
Ø5/8
45° X 1/16
1-21/32
1-1/8
3/4
0.38
0.19
3/32
0.39
0.60
0.28
TO REAM Ø0.093
Ø1-1/16
℄
℄

ORIGINAL

Scale: 2:1	Quantity: 1	Units: Inch
Material: Stainless steel - -		
Surface treatment: Non		

Tolerances after any surface treatment
x/x ± 1/32
x.x ± 0.010
x.xx ± 0.005
x.xxx ± 0.002
∠90° ± 1/4°
roughness average:

INO

369, Franquet St.
Sainte-Foy, Québec
Canada, G1P 4N8
Tel: (418) 657-7006
F

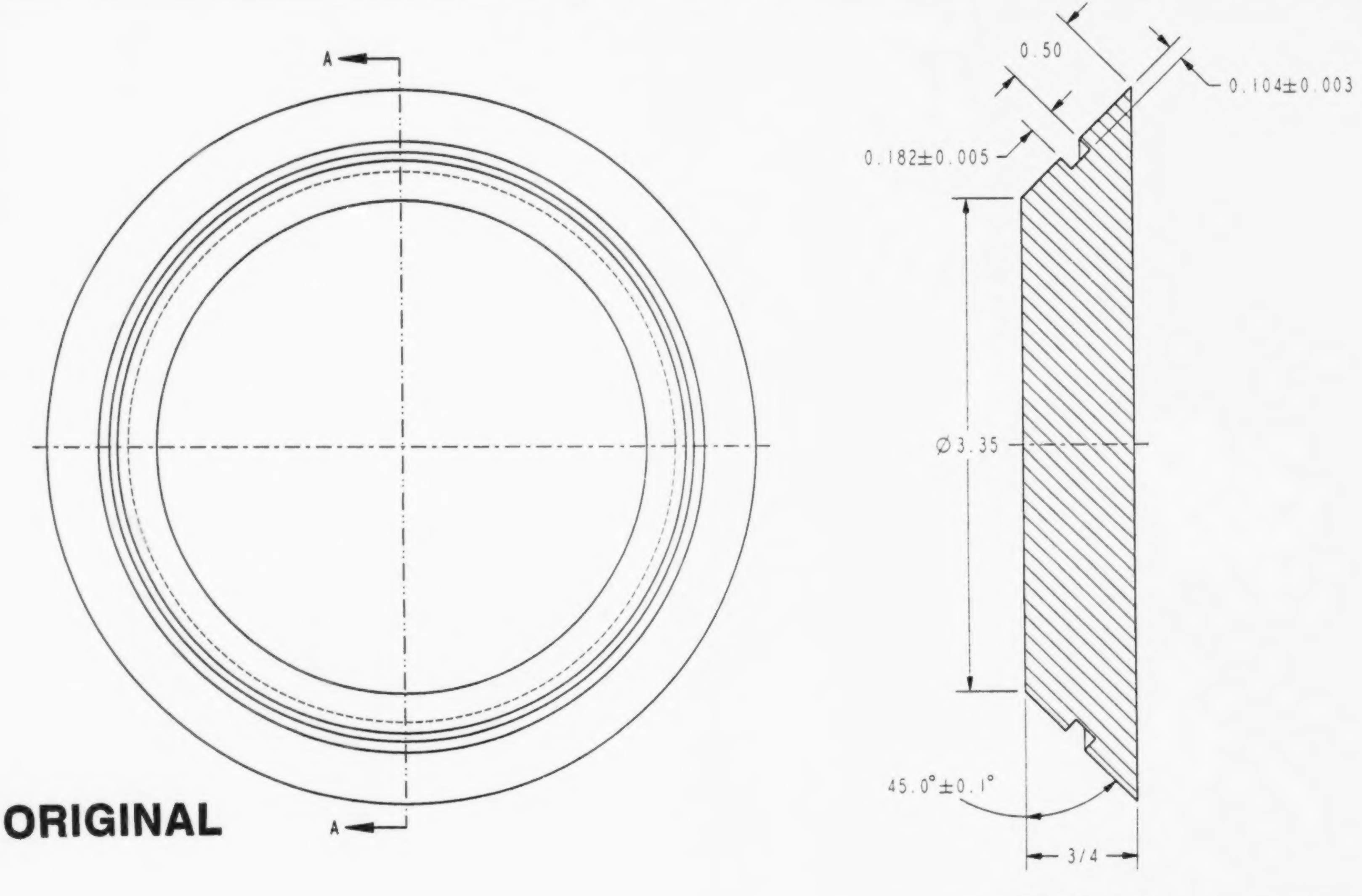
PULLING HOOK, PART #2

Designed: S. Roy	Verified:
Drawn: S. Roy	Approved:
Sheet 1 of 1	Software: Pro/E 2000i
	Size A

Sep-

MP A

Rev pti D



SECTION A-A

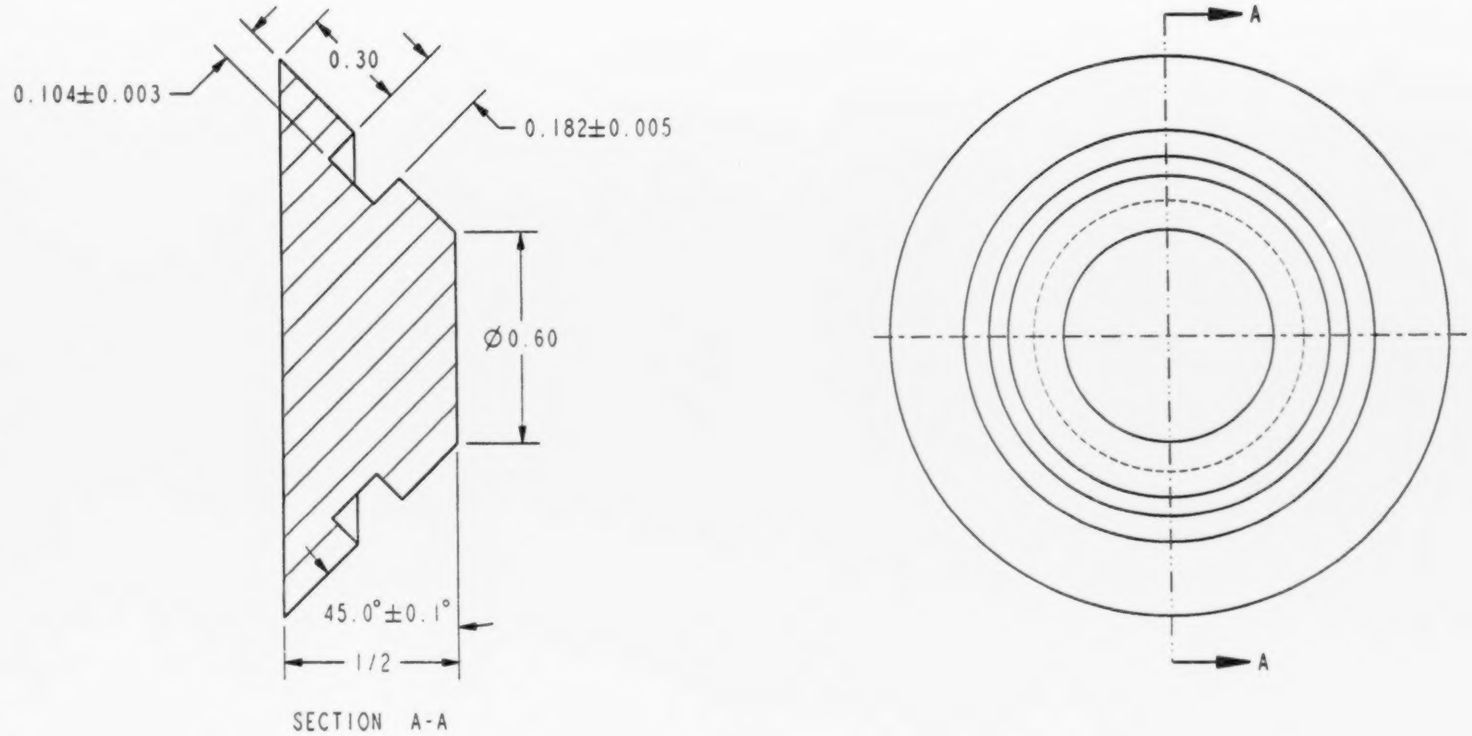
ORIGINAL

NOTE : PLEASE LEAVE ON PROTECTOR FILM
ON THE PIECE WHEN MACHINING.

vision	Description	Date	By

Scale: 1:1	Quantity 3	Units: Inch	Tolerances after any surface treatment	INO	RECEPTION WINDOW		
Material: Lexan - -			x/x ± 1/32 x.x ± 0.010 x.xx ± 0.005 x.xxx ± 0.002 ∠90° ± 1/4° roughness average: 63√	369, Franquet St. Sainte-Foy, Québec Canada, G1P 4N8 Tel: (418) 657-7006 Fax: (418) 657-7009	Designed: P. Gagnon	Verified:	
					Drawn: L. Simard	Approved:	
Surface treatment: None					Sheet 1 of 1	Software: Pro/E 2000i	Size A
					10-Sep-99	7737-MPC045A	

FENETRE RECEPTION



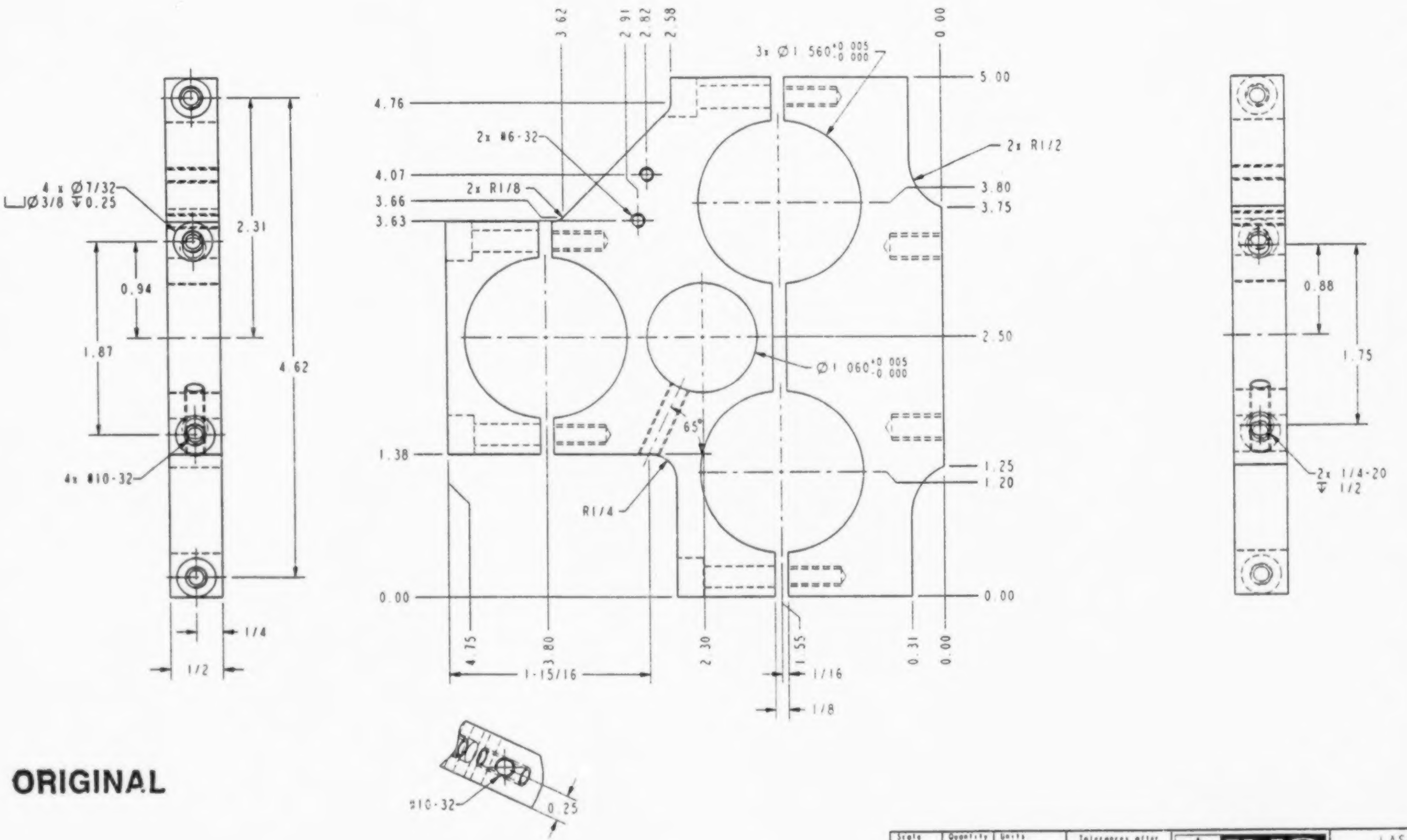
SECTION A-A

ORIGINAL

TE : PLEASE LEAVE ON PROTECTOR FILM
ON THE PIECE WHEN MACHINING.

Scale: 2:1	Quantity 1	Units: Inch	Tolerances after any surface treatment x/x ± 1/32 x.x ± 0.010 x.xx ± 0.005 x.xxx ± 0.002 ∠90° ± 1/4° roughness average: 63√	INO 369, Franquet St. Sainte-Foy, Québec Canada, G1P 4N8 Tel: (418) 657-7006 Fax: (418) 657-7009	CAMERA WINDOW	
Material: Lexan - -					Designed: P. Gagnon	Verified: P.A.
					Drawn: L. Simard	Approved: A.W.
Surface treatment: None					Sheet 1 of 1	Software: Pro/E 2000i Size A
					10-Sep-99	7727-MPC[illegible]

vision	Description	Date	By


4 x Ø7/32
⌴Ø3/8 ↧0.25
2.31
0.94
1.87
4.62
4x #10-32
1/4
1/2
3.62
2.91
2.82
2.58
0.00
3x Ø1.560 +0.005 -0.000
5.00
2x R1/2
3.80
3.75
4.76
2x #6-32
4.07
2x R1/8
3.66
3.63
2.50
Ø1.060 +0.005 -0.000
65°
1.38
R1/4
1.25
1.20
0.00
0.00
4.75
3.80
1-15/16
2.30
1.55
1/16
1/8
0.31
0.00
0.88
1.75
2x 1/4-20
↧ 1/2
#10-32
0.25

ORIGINAL

Revision	Description	Date	By

Scale	Quantity	Units
1:1	1	Inch

Material
Aluminum 6061-T6

Surface treatment
None

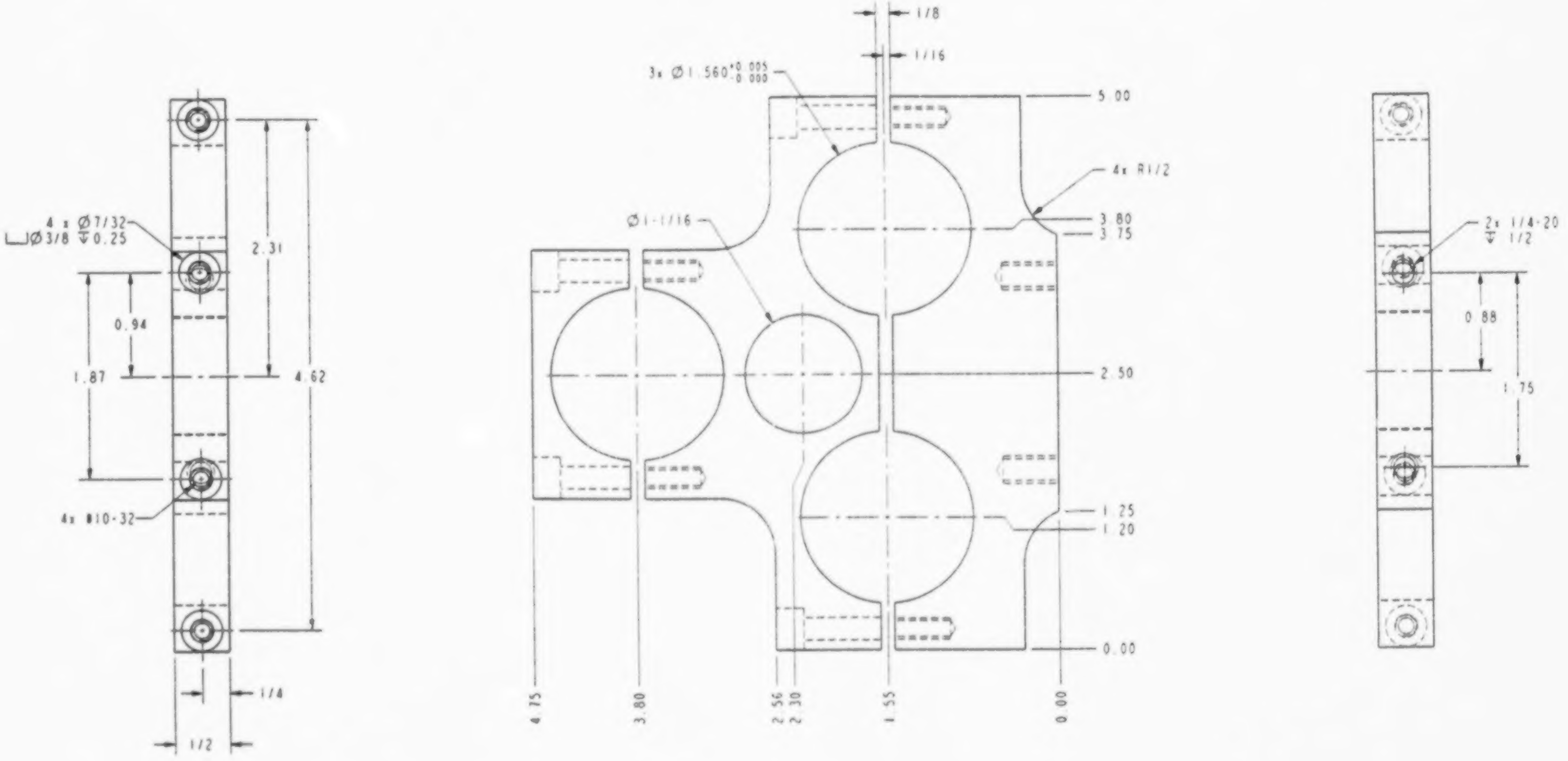
Tolerances after any surface treatment
x/x ± 1/32
x.x ± 0.010
x.xx ± 0.005
x.xxx ± 0.002
∠90° ± 1/4°
roughness average 63/

INO
369, Franquet St
Sainte-Foy, Quebec
Canada, G1P 4N8
Tel (418) 657-7006
Fax (418) 657-7009

LASERS HOLDER #1

Designed S. Roy	Verified P.D.
Drawn S. Roy	Approved Q.W
Sheet 1 of 1	Software Pro/E 2000i
28-Sep-99	7737-MPC047A

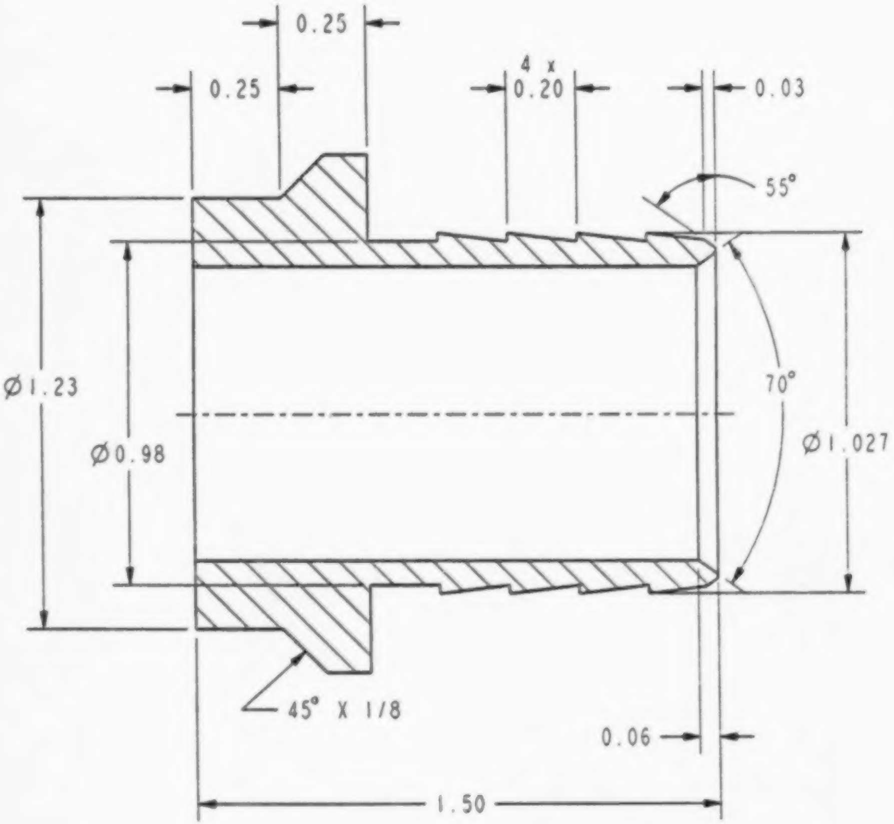
Size
B


1/8
1/16
3x Ø1.560 +0.005 -0.000
5.00
4x R1/2
3.80
3.75
Ø1-1/16
2.50
1.25
1.20
0.00
4.75
3.80
2.56
2.30
1.55
0.00
4 x Ø7/32
⌴Ø3/8 ↧0.25
2.31
0.94
1.87
4.62
4x #10-32
1/4
1/2
2x 1/4-20
↧ 1/2
0.88
1.75

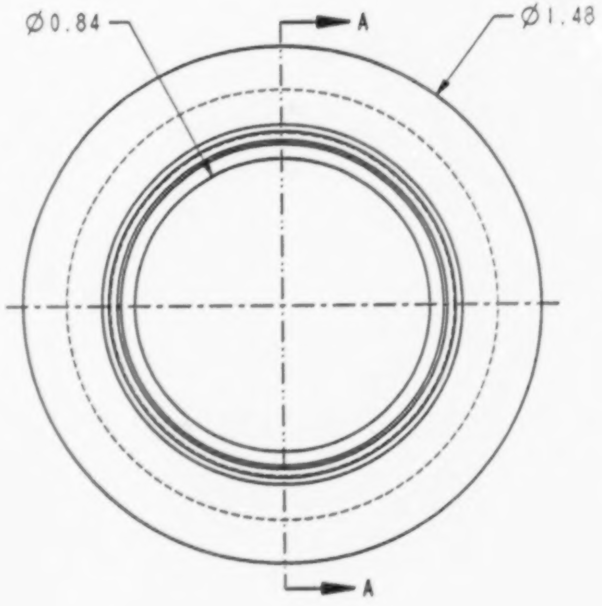
ORIGINAL

Scale	Quantity	Units	Tolerances after any surface treatment	INO	LASERS HOLDER #2		
1:1	1	Inch	x/x ± 1/32 x.x ± 0.010 x.xx ± 0.005 x.xxx ± 0.002 ∠90° ± 1/4° roughness average 63√	369, Franquet St Sainte-Foy, Quebec Canada, G1P 4N8 Tel: (418) 657-7006 Fax: (418) 657-7009	Designed S. Roy	Verified	
Material Aluminum 6061-T6					Drawn S. Roy	Approved	
Surface treatment None					Sheet 1 of 1	Software Pro/E 2000i	Size B
					28-Sep-99	7737-MPC048A	

Revision	Description	Date	By


0.25
0.25
4 x
0.20
0.03
55°
70°
Ø1.23
Ø0.98
Ø1.027
45° X 1/8
0.06
1.50

SECTION A-A


Ø0.84
Ø1.48
A
A

ORIGINAL

evision	Description	Date	By

Scale: 2:1
Quantity: 2
Units: Inch
Material:
Stainless steel 316L
-
-
Surface treatment:
Black anodizing

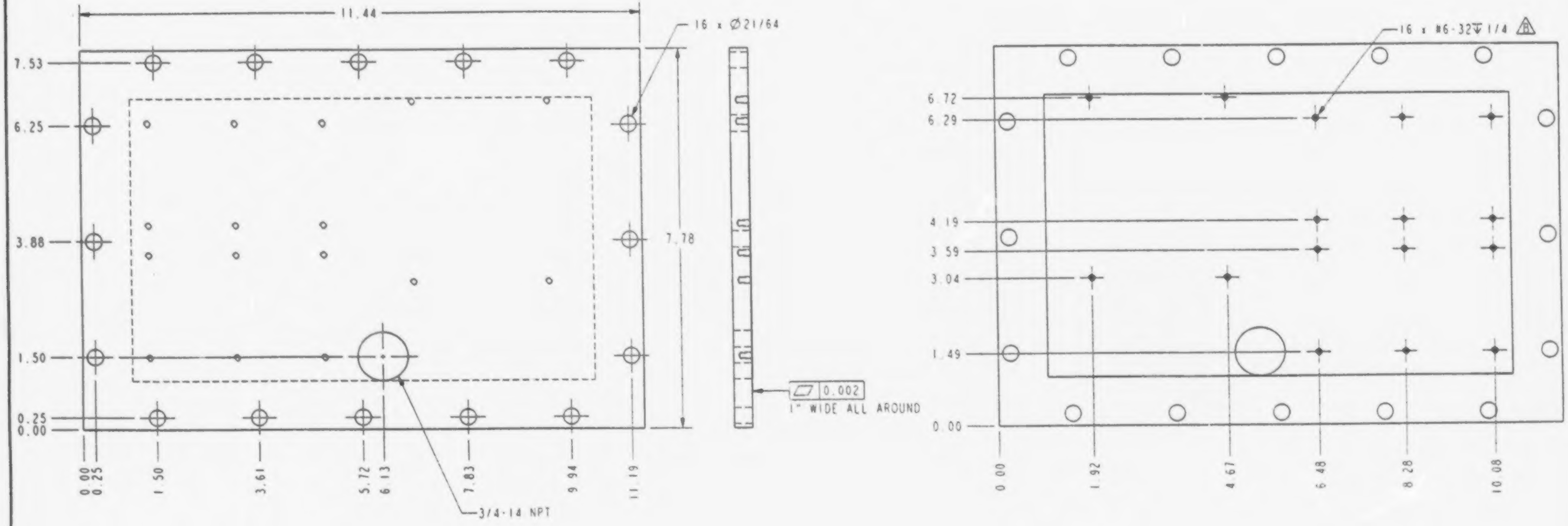
Tolerances after any surface treatment
x/x ± 1/32
x.x ± 0.010
x.xx ± 0.005
x.xxx ± 0.002
∠90° ± 1/4°
roughness average: 63/

INO

369, Franquet St
Sainte-Foy, Quebec
Canada, G1P 4N8
Tel: (418) 657-7006
Fax: (418) 657-7009

HOSE CONNECTOR
Designed: P. Gagnon
Verified:
Drawn: L. Simard
Approved:
Sheet 1 of 1
Software: Pro/E 2000i
Size: A
28-Sep-99
7737-MPC049A

CONNECTEUR_TUYAU


11.44
16 x Ø21/64
7.53
6.25
3.88
1.50
0.25
0.00
0.00
0.25
1.50
3.61
5.72
6.13
7.83
9.94
11.19
7.78
3/4-14 NPT
0.002
1" WIDE ALL AROUND
16 x #6-32 ↧ 1/4 B
6.72
6.29
4.19
3.59
3.04
1.49
0.00
0.00
1.92
4.67
6.48
8.28
10.08

ORIGINAL

Revision	Description	Date	By
B	HOLES ADDED	06/10/99	L.S.

Scale	Quantity	Units
1:2	1	inch

Material
Stainless steel 316L
Pl 3/8

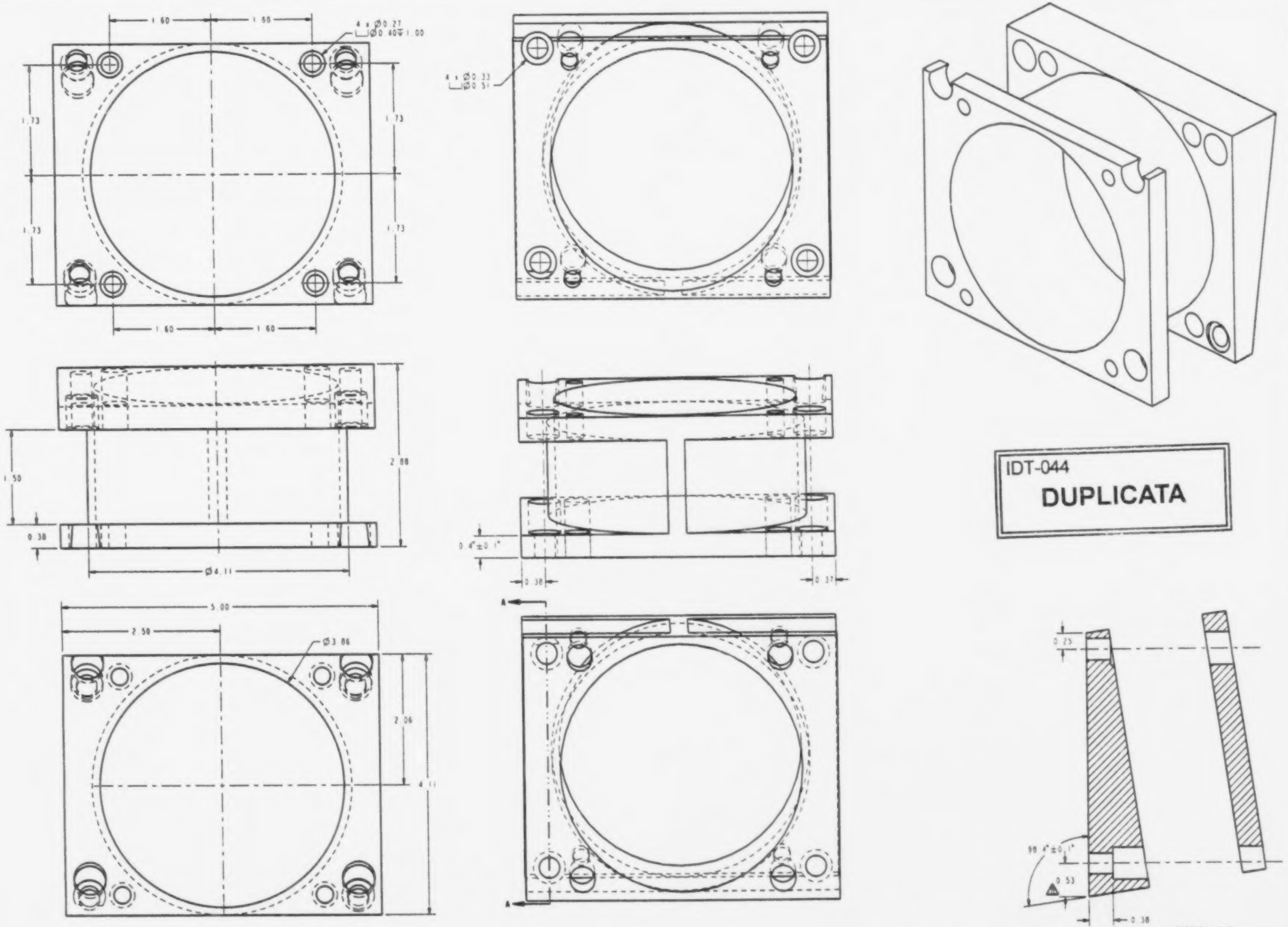
Surface treatment
None

Tolerances after any surface treatment
x/x ± 1/32
x.x ± 0.010
x.xx ± 0.005
x.xxx ± 0.002
∠90° ± 1/4°
roughness average 63/√

INO
369, Franquet St
Sainte-Foy, Québec
Canada, G1P 4N8
Tel. (418) 657-7006
Fax. (418) 657-7009

REAR PLATE, HOUSING

Designed P. Gagnon	Verified
Drawn L. Simard	Approved
Sheet 1 of 1	Software Pro/E 2000i · Size B
06-Oct-99	7737-MPC050B


1.60
1.60
4 x Ø0.27
⌴Ø0.40↧1.00
1.73
1.73
1.73
1.73
1.60
1.60
4 x Ø0.33
⌴Ø0.51
1.50
2.88
0.38
Ø4.11
0.4°±0.1°
0.38
0.37
A
A
5.00
2.50
Ø3.86
2.06
4.11
0.25
98.4°±0.1°
0.53
0.38
SECTION A-A

IDT-044
DUPLICATA

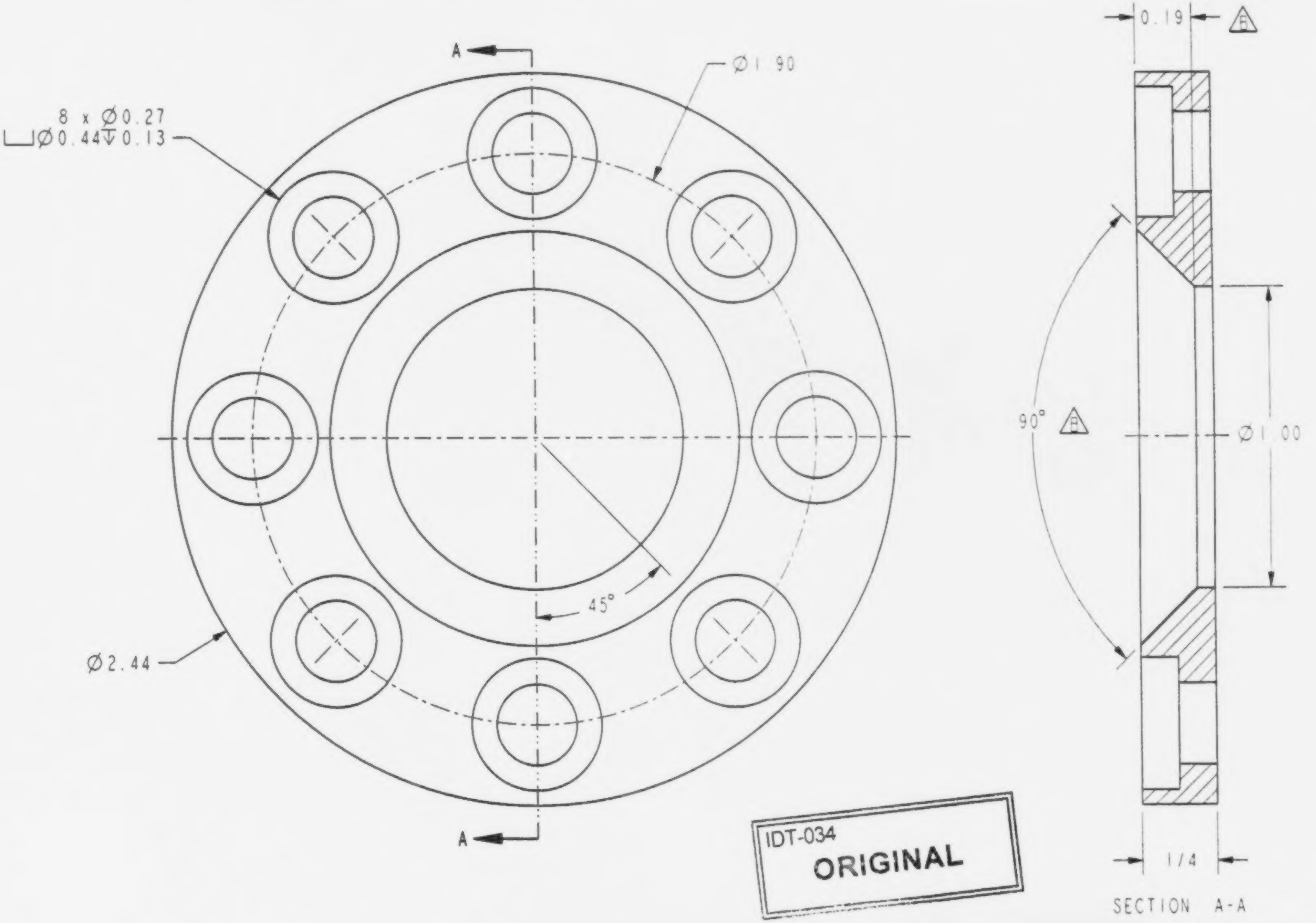
B	HOLES MOVED	01/10/99	L.S.
Revision	Description	Date	By

Scale 1:1
Quantity 1
Units Inch
Material
Aluminium 6061-T6
Surface treatment
None

Tolerance after any surface treatment
x/x ± 1/32
x.x ± 0.010
x.xx ± 0.005
x.xxx ± 0.002
∠90° ± 1/2°
roughness average

INO
369 Franquet St
Sainte-Foy, Québec
Canada, G1P 4N8
Tel: (418) 657-7006
Fax: (418) 657-7009

HOLDER, RECEPTION #1
Designed P. Gagnon
Verified
Drawn L. Simard
Approved
Sheet 1 of 1
Software Pro/E 2000i
Size C
28-Sep-99
7737-MPC0528



IDT-034
ORIGINAL

				Scale: 2:1	Quantity 1	Units: Inch	Tolerances after any surface treatment x/x ± 1/32 x.x ± 0.010 x.xx ± 0.005 x.xxx ± 0.002 ∠90° ± 1/4° roughness average: [redacted]
				Material: Stainless steel 316L - -			
B	HOLE MODIFIED	13/04/00	L.S.	Surface treatment: None [redacted] [redacted] [redacted]			
vis [redacted] [redacted]	De [redacted] tion [redacted] [redacted]	Da [redacted]	B [redacted]				

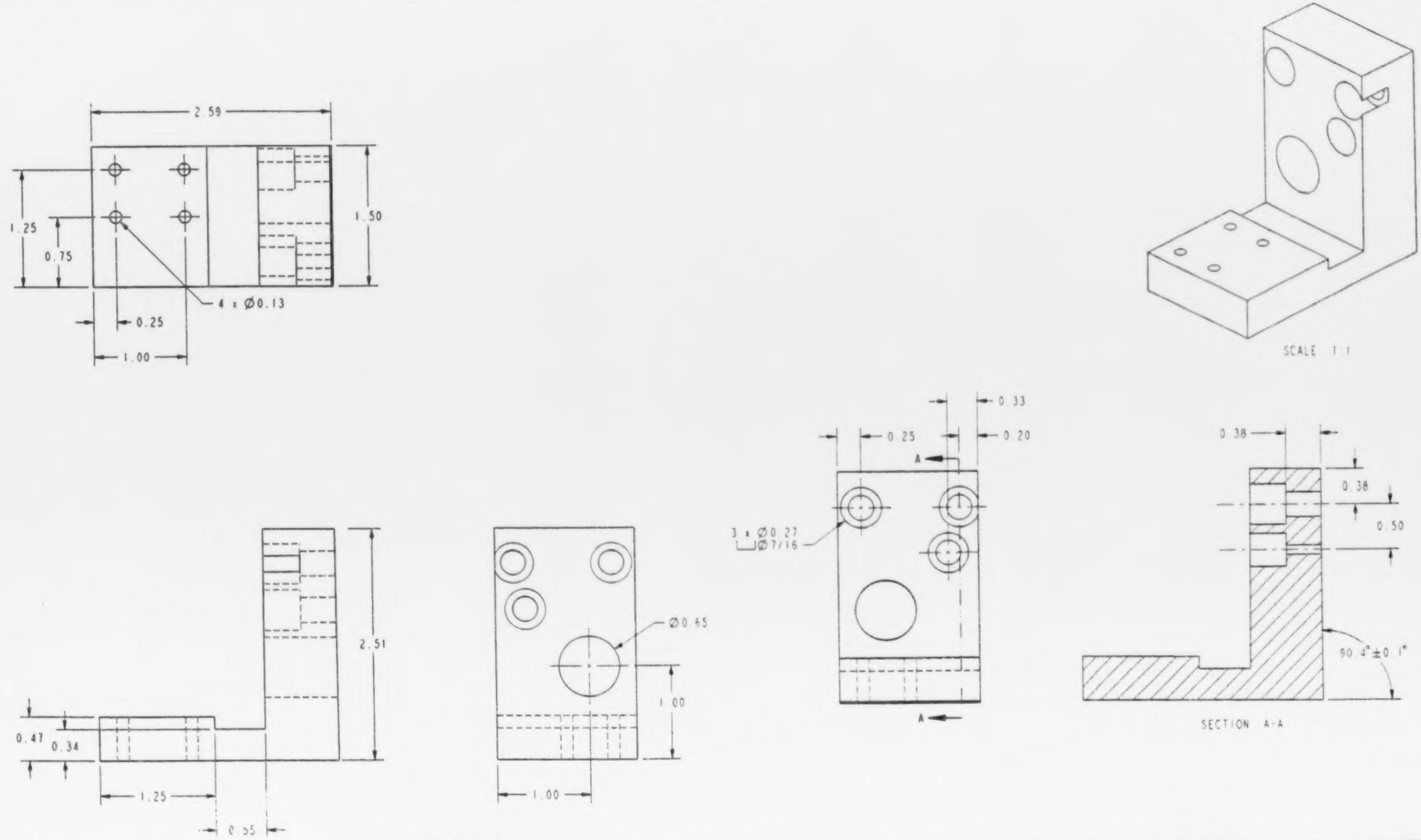
INO

369, Franquet St.
Sainte-Foy, Québec
Canada, G1P 4N8
Tel: (418) 657-7006
Fa [redacted]) 657 [redacted]

WINDOW RING, CAMERA

Designed: P. Gagnon	Verified: LL
Drawn: L. Simard	Approved: P.H.
Sheet 1 of 1	Software: Pro/E 2000i
Size A	
[redacted] ep-9 [redacted]	7 [redacted] MPC [redacted] 8 [redacted]

E FENETRE CAMERA


2.59
1.50
1.25
0.75
4 x Ø0.13
0.25
1.00
SCALE 1:1
0.33
0.25
0.20
A
A
3 x Ø0.27
Ø7/16
0.38
0.38
0.50
90.4°±0.1°
SECTION A-A
Ø0.65
2.51
1.00
1.00
0.47
0.34
1.25
0.55

ORIGINAL

Revision	Description	Date	By

Scale	Quantity	Units
1:1	1	Inch

Material
Aluminium 6061-T6

Surface treatment
None

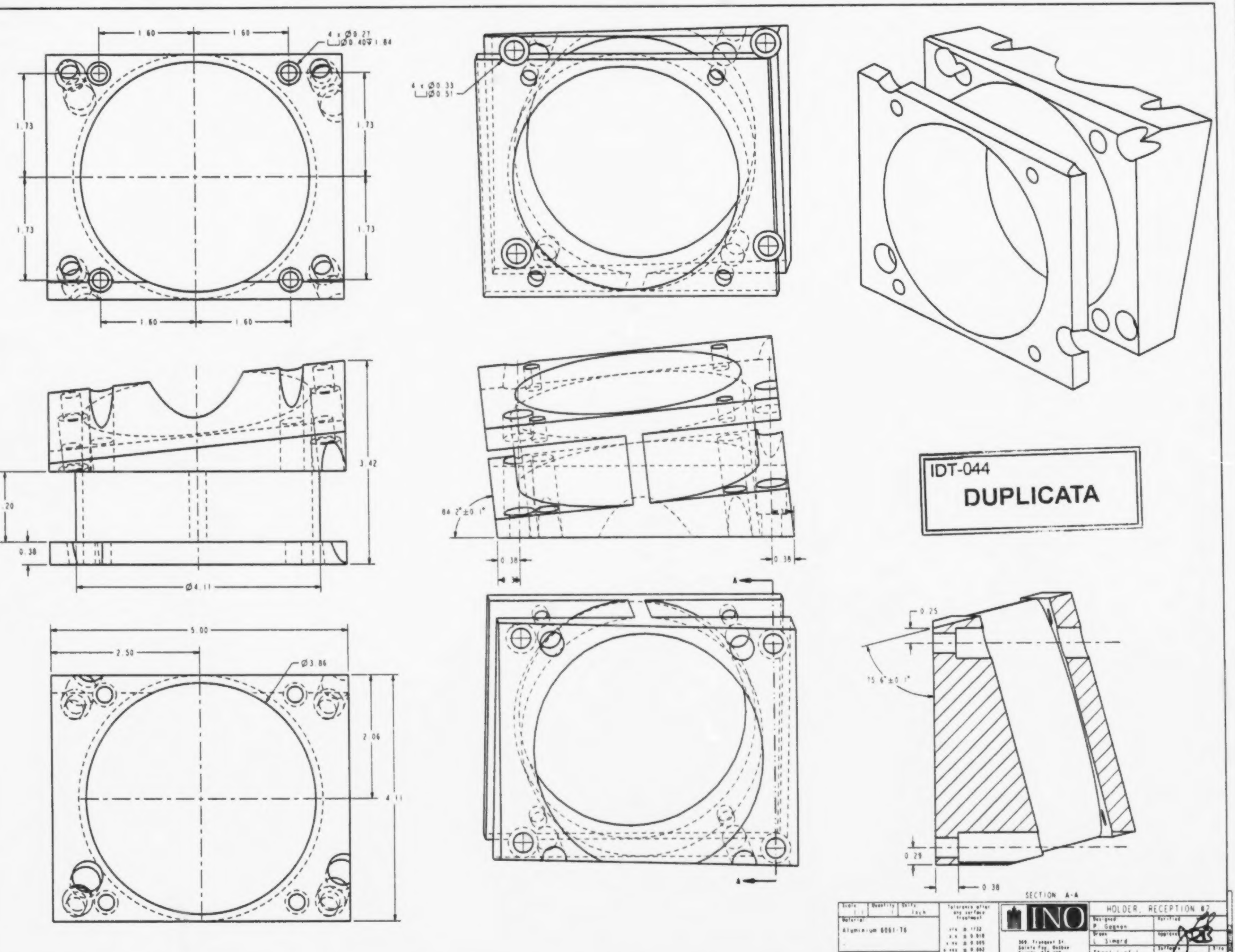
Tolerances after any surface treatment
x/x ± 1/32
x.x ± 0.010
x.xx ± 0.005
x.xxx ± 0.002
∠90° ± 1/4°
roughness average 63√

INO
369, Franquet St
Sainte-Foy, Québec
Canada, G1P 4N8
Tel (418) 657-7006
Fax (418) 657-7009

HOLDER, EMISSION #1

Designed P. Gagnon	Verified J.L.
Drawn L. Simard	Approved J.W.
Sheet 1 of 1	Software Pro/E 2000i
29-Sep-99	7737-MPC054A

Size
B

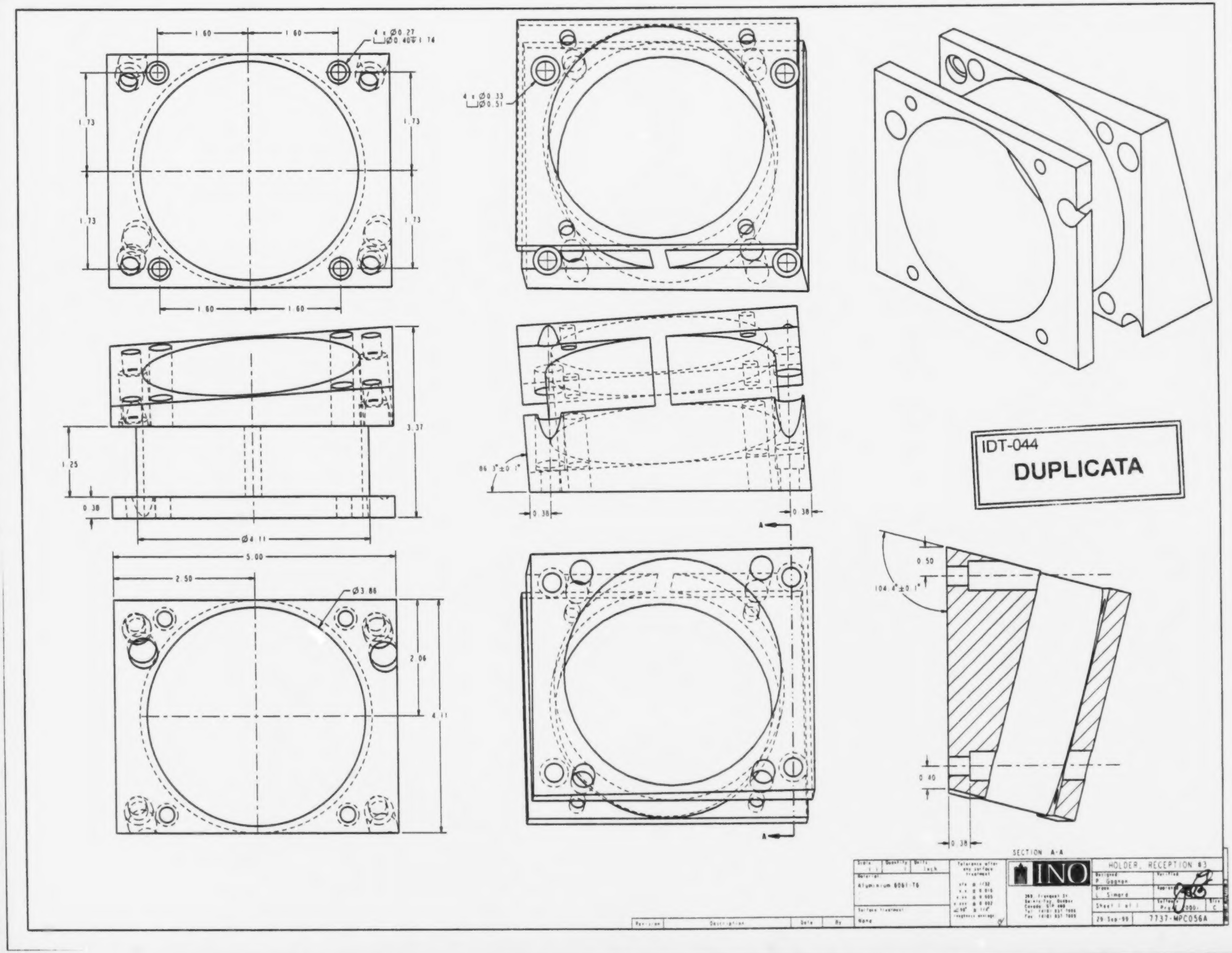

1.60
1.60
4 x Ø0.27
⌴Ø0.40 ↧1.84
1.73
1.73
1.73
1.73
1.60
1.60
4 x Ø0.33
⌴Ø0.51
3.42
1.20
0.38
Ø4.11
84.2°±0.1°
0.38
0.38
A
A
5.00
2.50
Ø3.86
2.06
4.11
0.25
75.6°±0.1°
0.29
0.38
SECTION A-A

IDT-044
DUPLICATA

Scale 1:1	Quantity 1	Units Inch	Tolerance after any surface treatment x/x ± 1/32 x.x ± 0.010 x.xx ± 0.005 x.xxx ± 0.002 ∠90° ± 1/2° roughness average:	INO 369, Franquet St. Sainte-Foy, Québec Canada, G1P 4N8 Tel (418) 657-7006 Fax (418) 657-7009
Material Aluminium 6061-T6				
Surface treatment None				

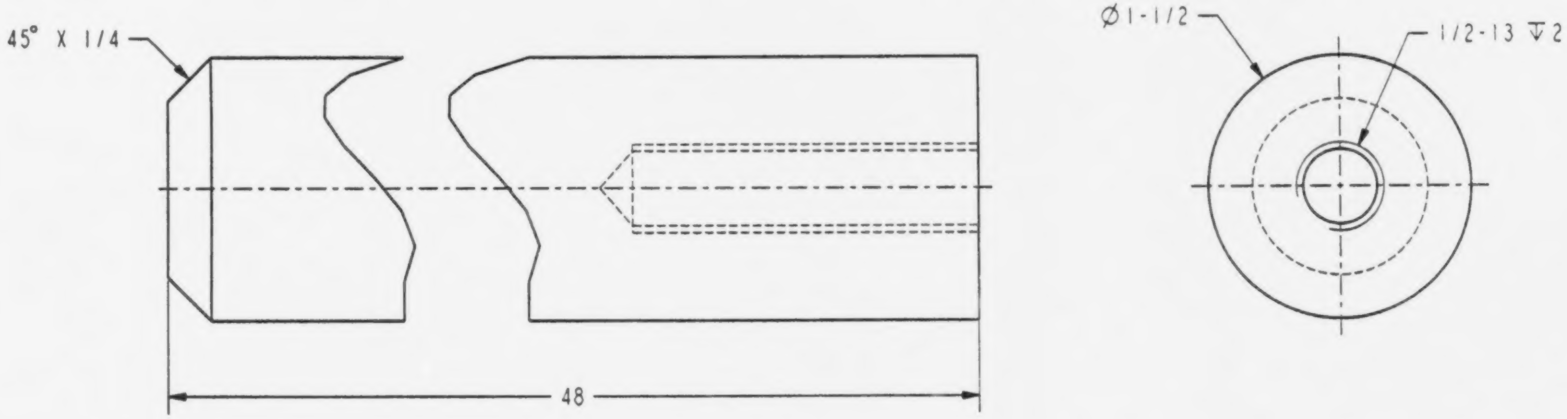
Revision	Description	Date	By

HOLDER, RECEPTION #2		
Designed P. Gagnon	Verified	
Drawn L. Simard	Approved	
Sheet 1 of 1	Software Pro/E 2000i	Size C
29-Sep-99	7737-MPC055A	



1.60
1.60
4 x Ø0.27
⌴Ø0.40↧1.74
1.73
1.73
1.73
1.73
1.60
1.60
4 x Ø0.33
⌴Ø0.51
3.37
1.25
0.38
Ø4.11
86.3°±0.1°
0.38
0.38
A
A
5.00
2.50
Ø3.86
2.06
4.11
0.50
104.4°±0.1°
0.40
0.38
SECTION A-A
Scale 1:1
Quantity 1
Units Inch
Material
Aluminium 6061-T6
Surface treatment
None
Tolerance after any surface treatment
Revision
Description
Date
By
INO
Sainte-Foy, Quebec
Canada
HOLDER, RECEPTION #3
Designed P. Gagnon
Verified
Drawn L. Simard
Approved
Sheet 1 of 1
Size C
29-Sep-99
7737-MPC056A

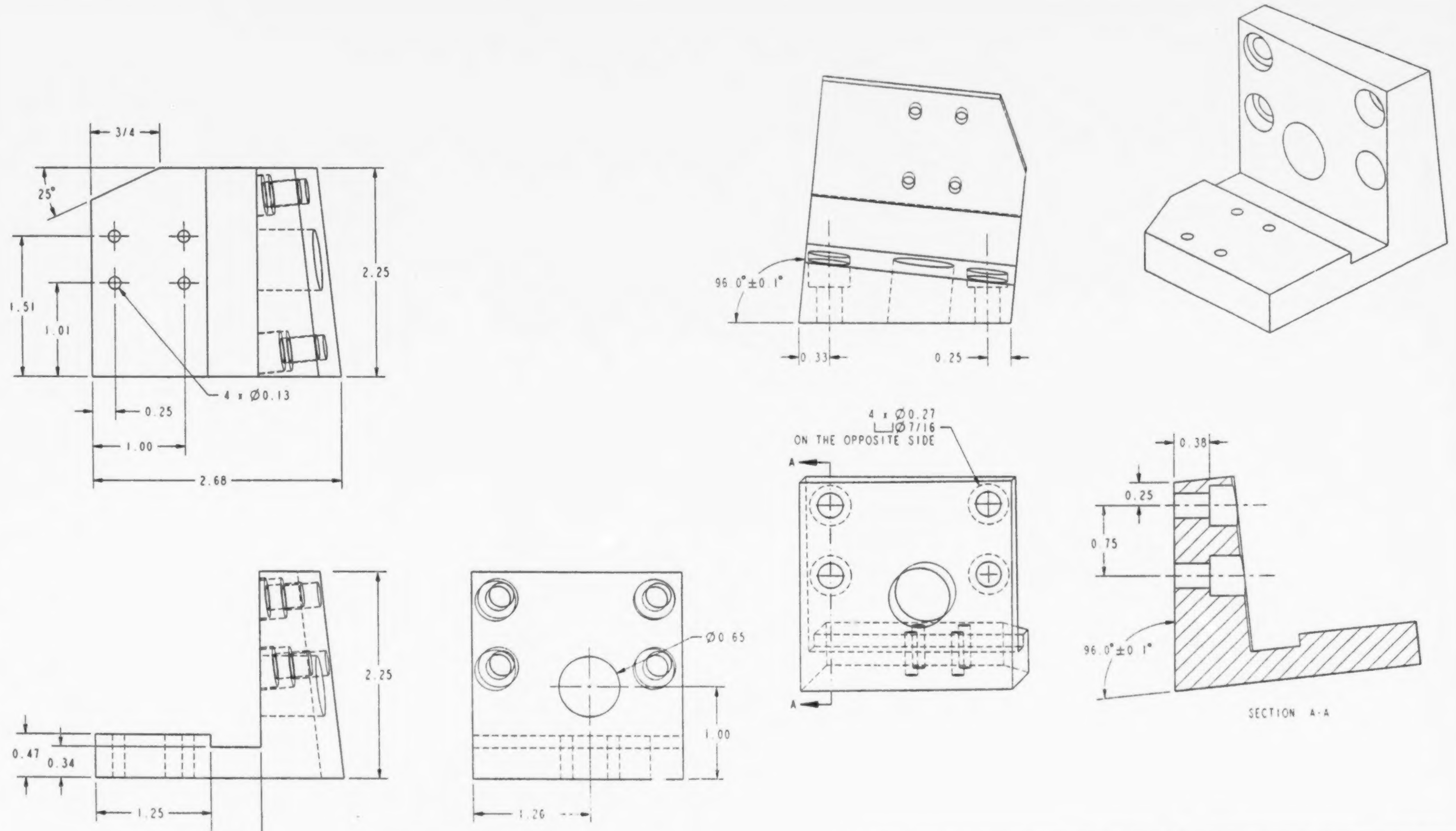
IDT-044
DUPLICATA



ORIGINAL

Scale: 1:1	Quantity: 2	Units: Inch	Tolerances after any surface treatment x/x ± 1/32 x.x ± 0.010 x.xx ± 0.005 x.xxx ± 0.002 ∠90° ± 1/4° roughness average:	INO 369, Franquet St. Sainte-Foy, Québec Canada, G1P 4N8 Tel: (418) 657-7006 Fa 657	INSTALLATION ROD
Material: Aluminum 6061-T6 - -					Designed: P. Gagnon Verified: P.L
					Drawn: S. Roy Approved:
Surface treatment: None					Sheet 1 of 1 Software: Pro/E 2000i Size A
					ep-9 7 MPO A

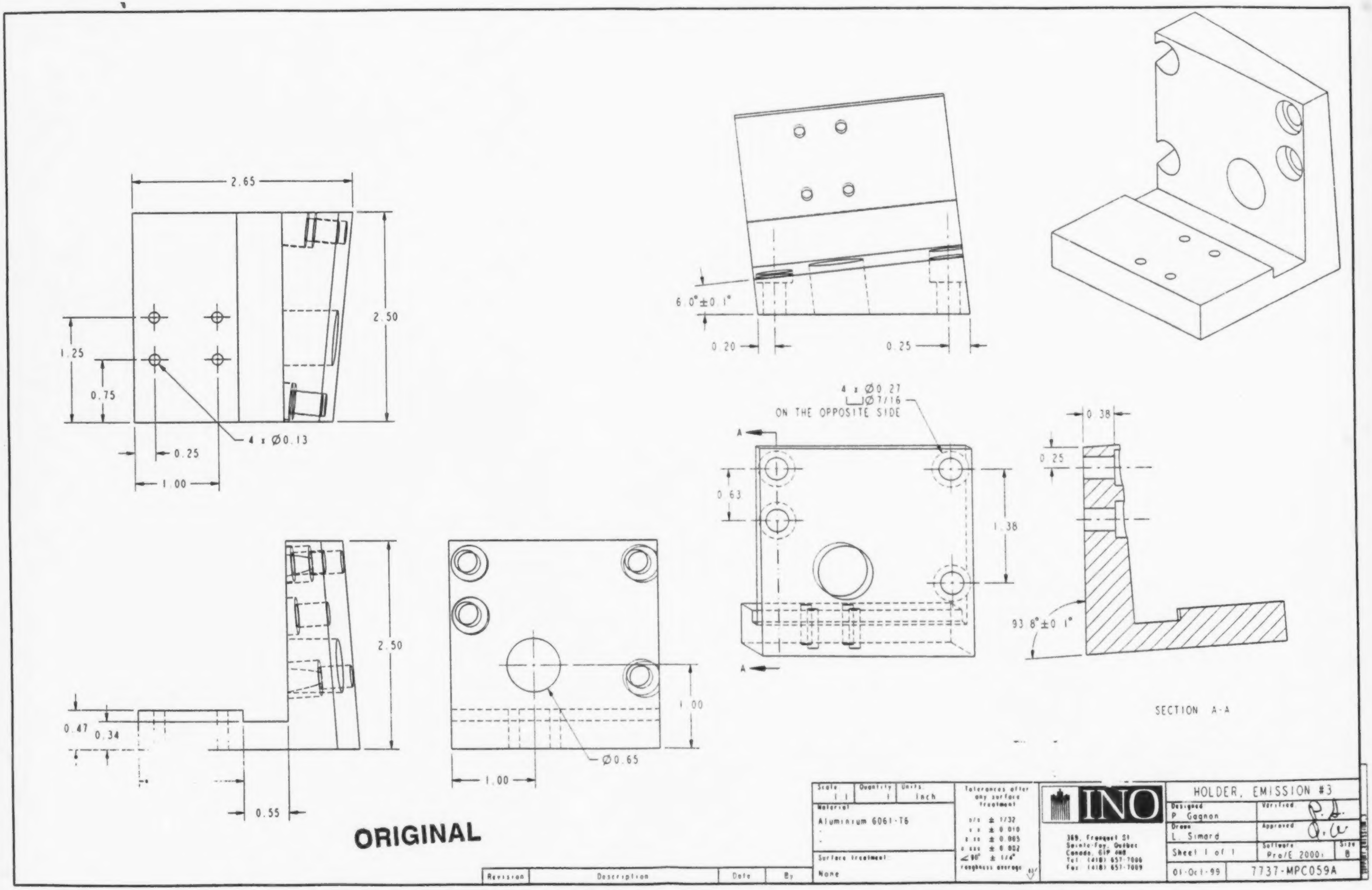
evis De tio Da B


3/4
25°
1.51
1.01
2.25
4 x Ø0.13
0.25
1.00
2.68
96.0°±0.1°
0.33
0.25
4 x Ø0.27
⌴Ø7/16
ON THE OPPOSITE SIDE
A
A
0.38
0.25
0.75
96.0°±0.1°
SECTION A-A
0.47
0.34
1.25
0.55
2.25
Ø0.65
1.00
1.26

ORIGINAL

Scale 1:1	Quantity 1	Units Inch	Tolerances after any surface treatment x/x ± 1/32 x.x ± 0.010 x.xx ± 0.005 x.xxx ± 0.002 ∠90° ± 1/4° roughness average 63√	INO 369, Franquet St Sainte-Foy, Québec Canada, G1P 4N8 Tel: (418) 657-7006 Fax: (418) 657-7009	HOLDER, EMISSION #2
Material Aluminium 6061-T6					Designed P. Gagnon
					Verified
					Drawn L. Simard
					Approved
Surface treatment None					Sheet 1 of 1
					Software Pro/E 2000i
					Size B
					01-Oct-99
					7737-MPC058A

Revision	Description	Date	By


2.65
2.50
1.25
0.75
0.25
1.00
4 x Ø0.13
6.0°±0.1°
0.20
0.25
4 x Ø0.27
⌴Ø7/16
ON THE OPPOSITE SIDE
A
A
0.63
1.38
0.38
0.25
93.8°±0.1°
SECTION A-A
2.50
0.47
0.34
0.55
1.00
1.00
Ø0.65
ORIGINAL
Revision
Description
Date
By

HOLDER, EMISSION #3

Scale 1:1
Quantity 1
Units Inch

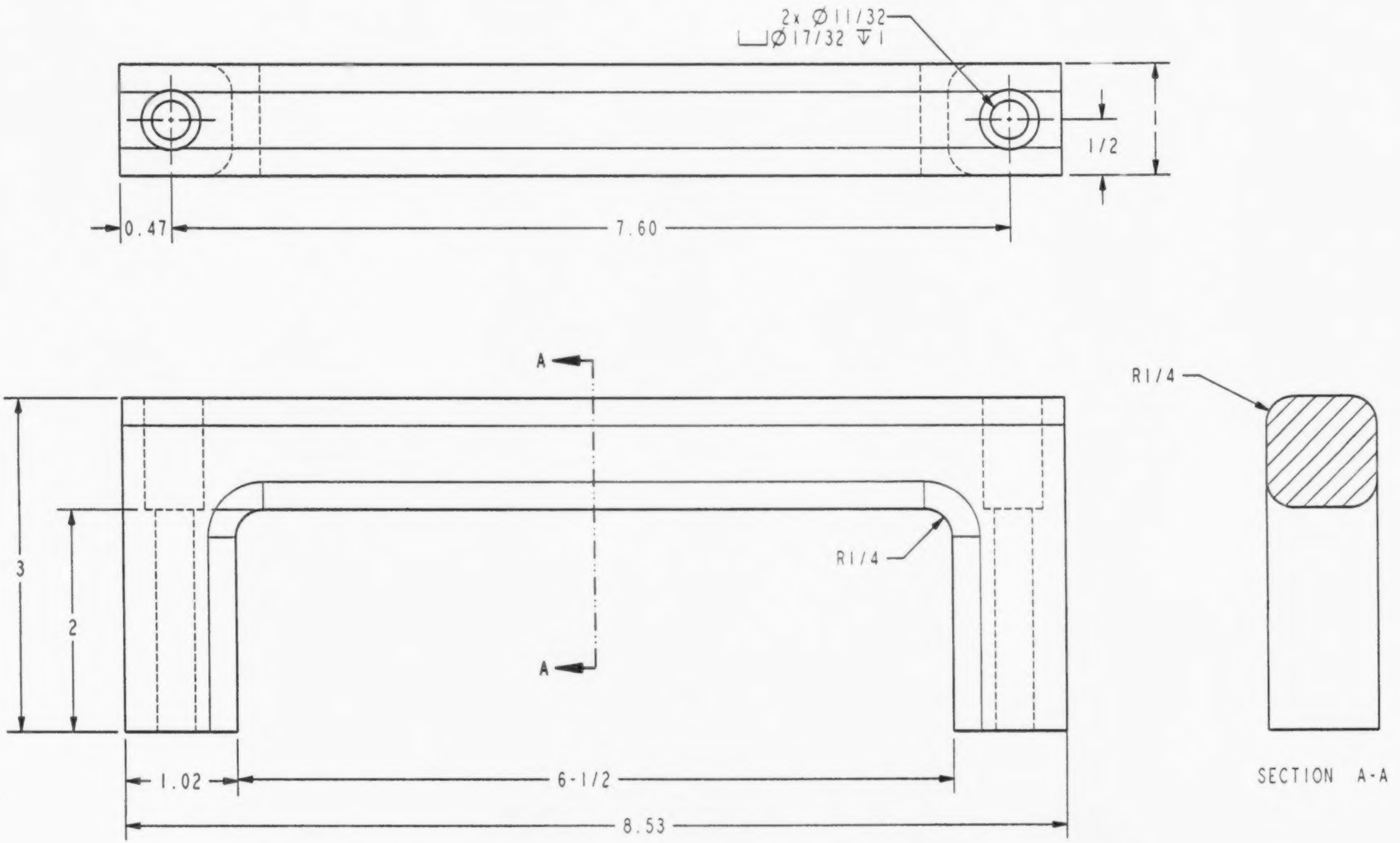
Material
Aluminium 6061-T6

Surface treatment
None

Tolerances after any surface treatment
x/x ± 1/32
x.x ± 0.010
x.xx ± 0.005
x.xxx ± 0.002
∠90° ± 1/4°
roughness average

INO
369, Franquet St
Sainte-Foy, Québec
Canada, G1P 4N8
Tel (418) 657-7006
Fax (418) 657-7009

Designed P. Gagnon
Verified P.L.
Drawn L. Simard
Approved J.W.
Sheet 1 of 1
Software Pro/E 2000i
Size B
01-Oct-99
7737-MPC059A


2x Ø11/32
⌴Ø17/32 ↧1
1/2
0.47
7.60
A
A
3
2
R1/4
1.02
6-1/2
8.53
R1/4
SECTION A-A

ORIGINAL

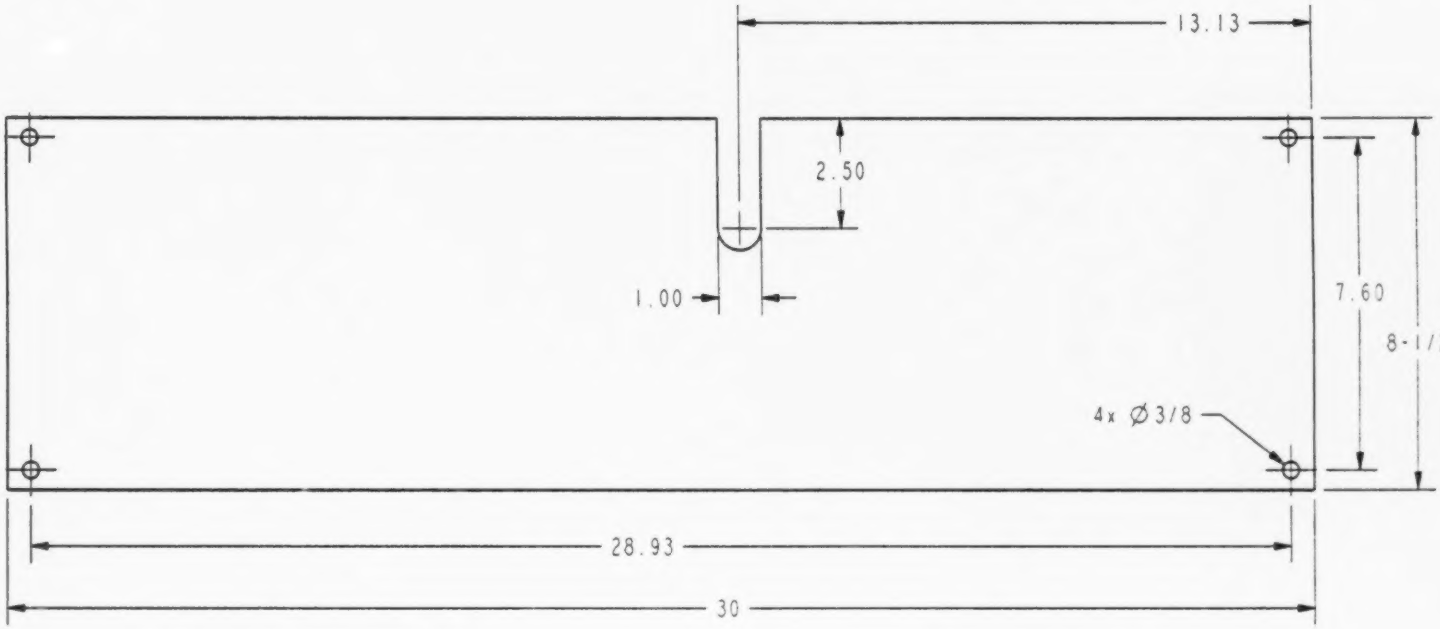
evision	Description	Date	By

Scale: 3:4
Quantity: 2
Units: Inch
Material:
Aluminum 6061-T6
-
-
Surface treatment:
None

Tolerances after any surface treatment
x/x ± 1/32
x.x ± 0.010
x.xx ± 0.005
x.xxx ± 0.002
∠90° ± 1/4°
roughness average: 63

INO
369, Franquet St.
Sainte-Foy, Québec
Canada, G1P 4N8
Tel: (418) 657-7006
Fax: (418) 657-7009

HANDLE
Designed: P. Gagnon
Verified:
Drawn: S. Roy
Approved:
Sheet 1 of 1
Software: Pro/E 2000i
Size: A
29-Sep-99
7737-MPC060A



ORIGINAL

Scale: 1:4	Quantity: 1	Units: Inch

Material:
Aluminum 6061-T6
Pl. 1/8
-

Surface treatment:
None[redacted]

Tolerances after any surface treatment
x/x ± 1/32
x.x ± 0.010
x.xx ± 0.005
x.xxx ± 0.002
∠90° ± 1/4°
rough[redacted]rage:

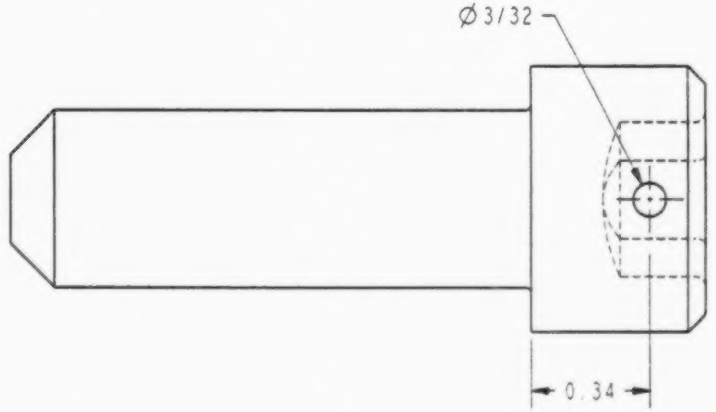
INO

369, Franquet St.
Sainte-Foy, Québec
Canada, G1P 4N8
Tel: (418) 657-7006
Fa[redacted]) 65[redacted]

PROTECTEUR

Designed: P. Gagnon	Verified: P.B.
Drawn: S. Roy	Approved:
Sheet 1 of 1	Software: Pro/E 2000i
	Size A

vis[redacted] [redacted] De[redacted]tio[redacted] [redacted] Da[redacted] B[redacted] [redacted] [redacted] [redacted] [redacted] [redacted] [redacted] [redacted]ep-9[redacted] 7[redacted]MPC[redacted]A [redacted]



ORIGINAL

evision	Description	Date	By

Scale: 2:1	Quantity: 8	Units: Inch
Material: Stainless steel - -		
Surface treatment: None		

Tolerances after any surface treatment
x/x ± 1/32
x.x ± 0.010
x.xx ± 0.005
x.xxx ± 0.002
∠90° ± 1/4°
roughness average: 63/

INO

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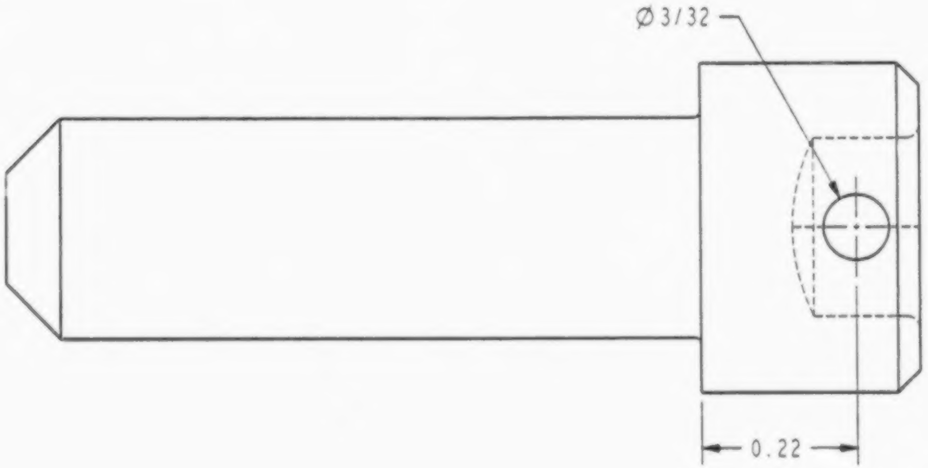
Fax: (418) 657-7009

BOLT 1/2-13 MODIFIED

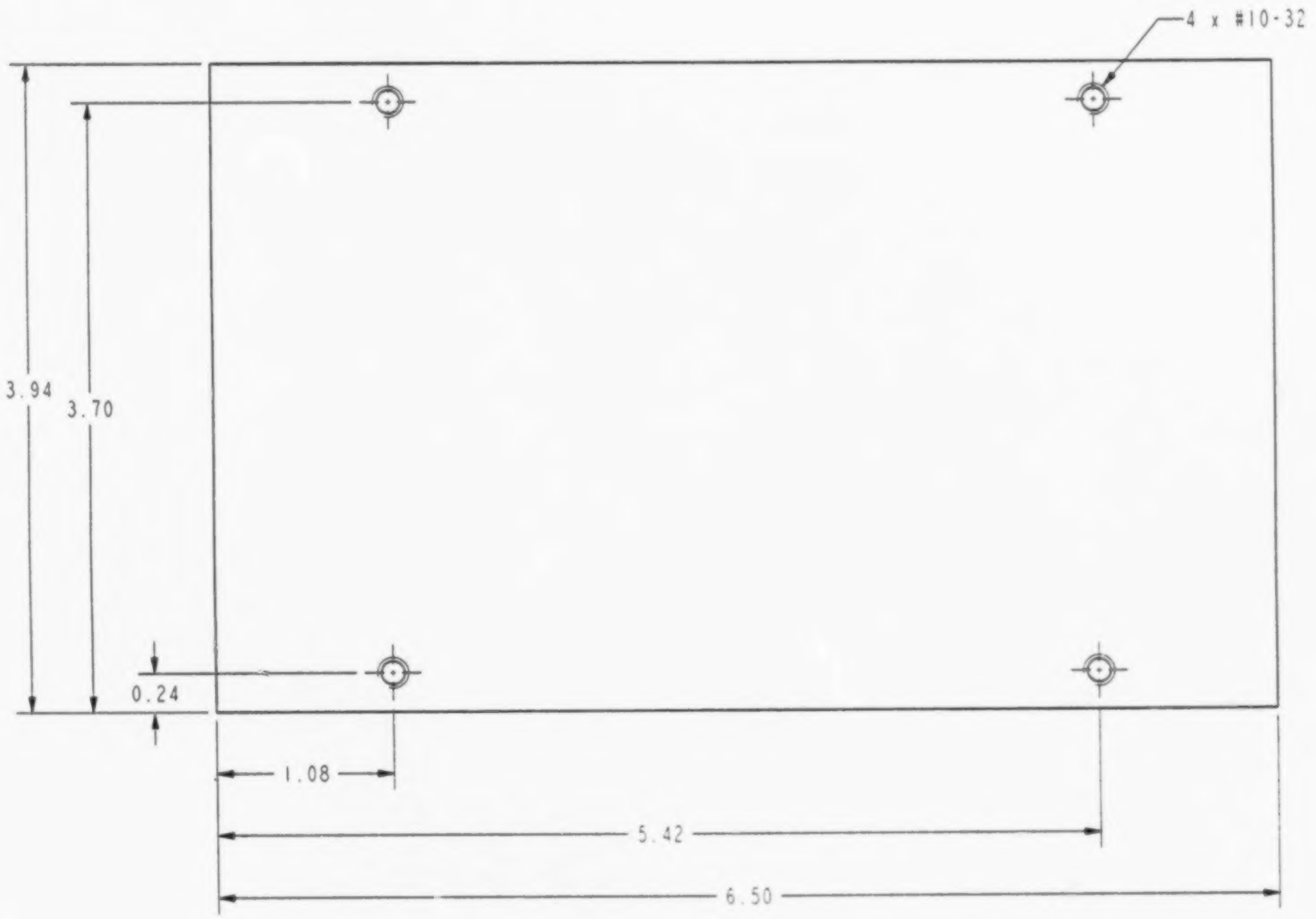
Designed: P. Gagnon	Verified:	
Drawn: S. Roy	Approved:	
Sheet 1 of 1	Software: Pro/E 2000i	Size A
01-Oct-99	7737-MPC062A	



ORIGINAL

Scale: 4:1	Quantity: -	Units: Inch	Tolerances after any surface treatment x/x ± 1/32 x.x ± 0.010 x.xx ± 0.005 x.xxx ± 0.002 ∠90° ± 1/4° roughness average: [redacted]	BOLT 5/16-18 MODIFIED
Material: stainless steel - -			INO 369, Franquet St. Sainte-Foy, Québec Canada, G1P 4N8 Tel: (418) 657-7006 F[redacted]	Designed: P. Gagnon Verified: P.A. Drawn: S. Roy Approved: d.W Sheet 1 of 1 Software: Pro/E 2000i Size A
Surface treatment: Non[redacted]				[redacted] Oct-[redacted] 7[redacted]-MPC[redacted]A [redacted]

evi[redacted] D[redacted]ptio[redacted] Da[redacted] B[redacted]



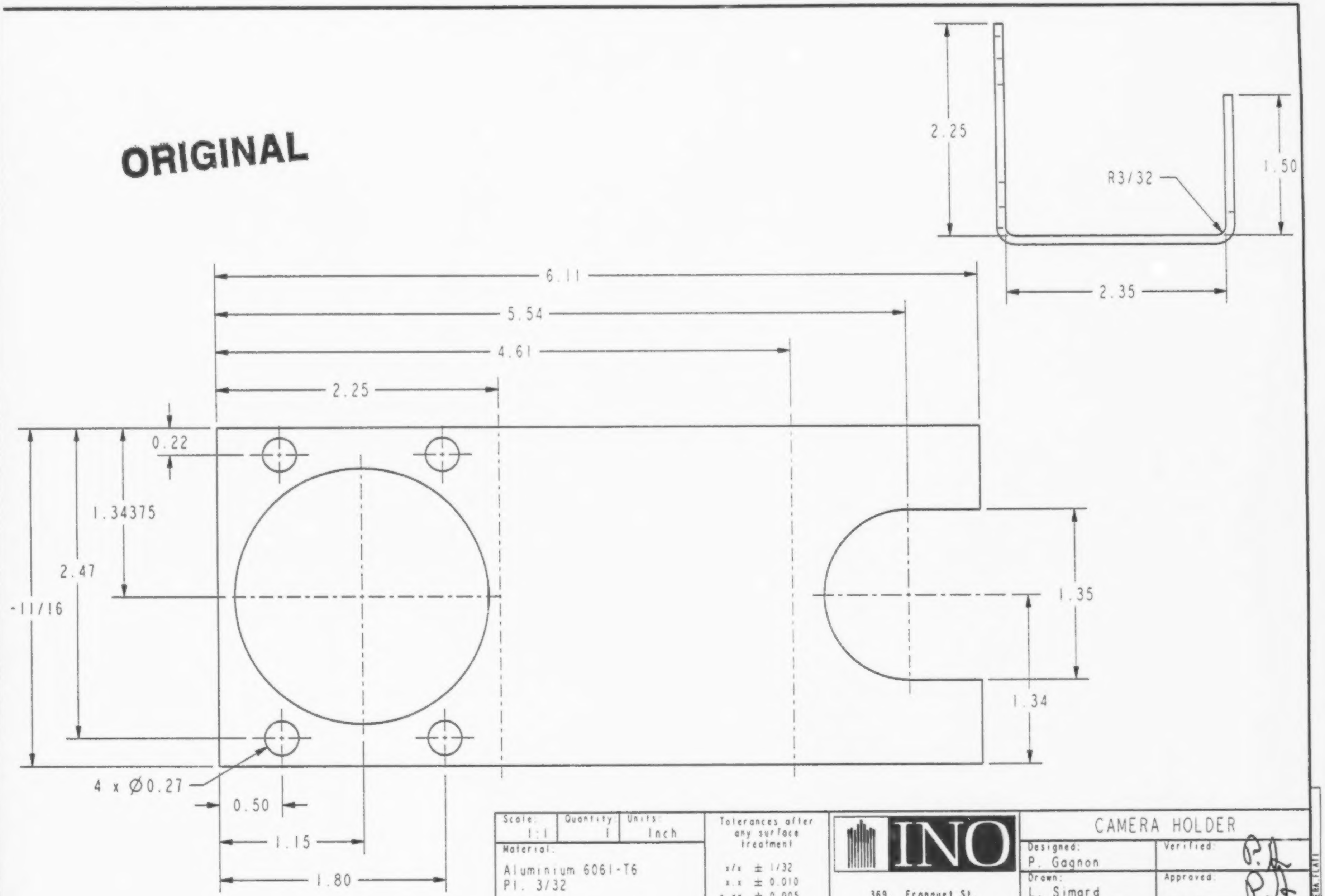
ORIGINAL

Scale 1:1	Quantity 1	Units: Inch	Tolerances after any surface treatment x/x ± 1/32 x.x ± 0.010 x.xx ± 0.005 x.xxx ± 0.002 ∠90° ± 1/4° roughness average 63√	**INO** 369, Franquet St. Sainte-Foy, Québec Canada, G1P 4N8 Tel: (418) 657-7006 Fax: (418) 657-7009	RECEPTION COVER
Material Aluminium 6061-T6 Pl. 1/8 -					Designed: P. Gagnon
Surface treatment None					Verified:
					Drawn: L. Simard
					Approved:
					Sheet 1 of 1
					Software: Pro/E 2000i
					Size A
					05-Oct-99
					7737-MPC067A

Revision	Description	Date	By

COUVERCLE RECEPTION

ORIGINAL


2.25
1.50
R3/32
2.35
6.11
5.54
4.61
2.25
0.22
1.34375
2.47
-11/16
1.35
1.34
4 x Ø0.27
0.50
1.15
1.80

Revision	Description	Date	By

Scale: 1:1
Quantity: 1
Units: Inch

Material:
Aluminium 6061-T6
Pl. 3/32
-

Surface treatment:
None

Tolerances after any surface treatment
x/x ± 1/32
x.x ± 0.010
x.xx ± 0.005
x.xxx ± 0.002
∠90° ± 1/4°
roughness average: 63√

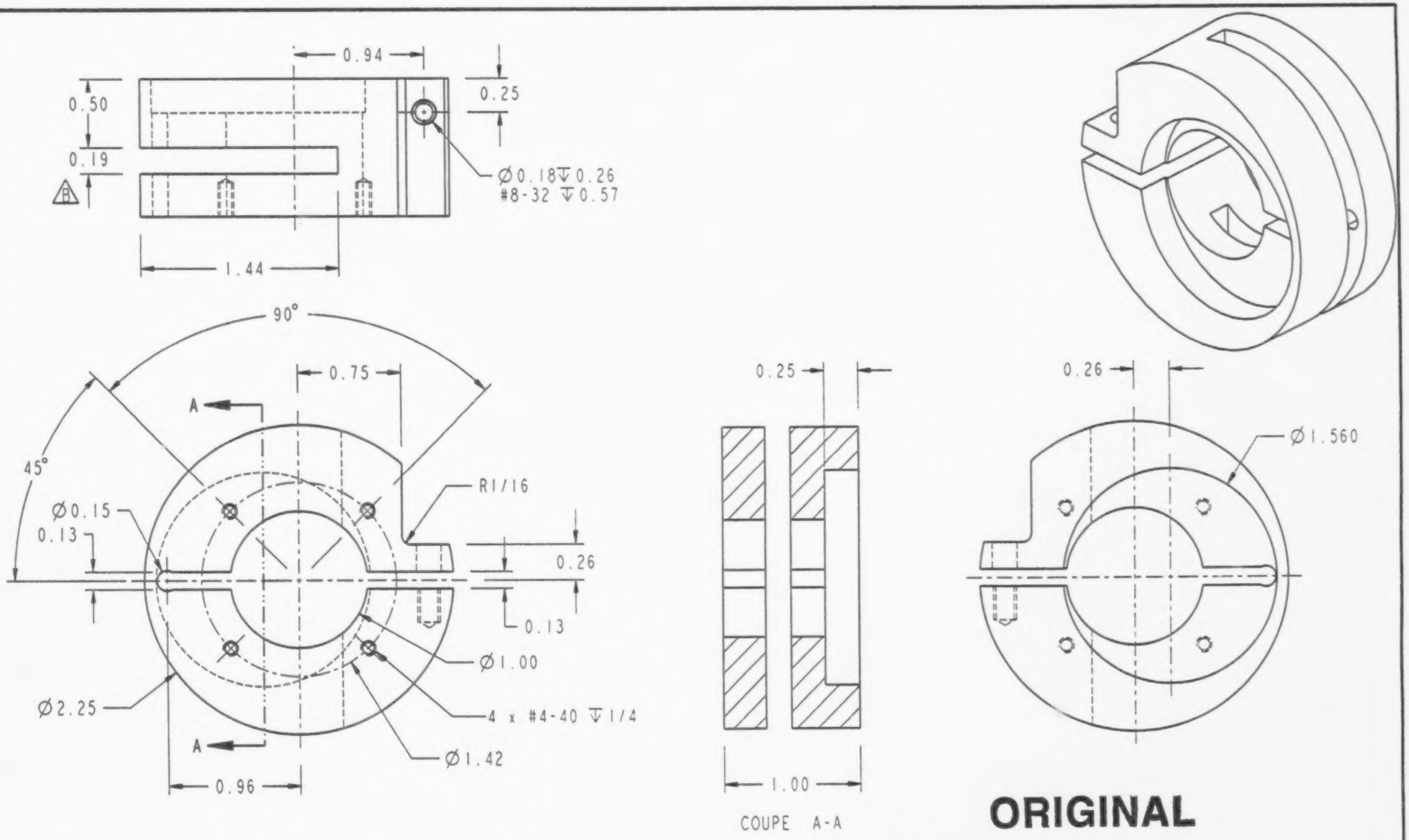
INO

369, Franquet St.
Sainte-Foy, Québec
Canada, G1P 4N8
Tel: (418) 657-7006
Fax: (418) 657-7009

CAMERA HOLDER

Designed: P. Gagnon
Verified:
Drawn: L. Simard
Approved:
Sheet 1 of 1
Software: Pro/E 2000i
Size A
07-Oct-99
7737-MPC068A

SUPPORT_CAMERA_PLATE


0.94
0.25
0.50
0.19
B
Ø0.18 ⩡ 0.26
#8-32 ⩡ 0.57
1.44
90°
0.75
A
45°
Ø0.15
0.13
R1/16
0.26
0.13
Ø1.00
4 x #4-40 ⩡ 1/4
Ø1.42
Ø2.25
A
0.96
0.25
1.00
COUPE A-A
0.26
Ø1.560

ORIGINAL

C	GENERAL	99/09/17	S.R.
B	ADDED SLOT	99/09/10	S.R.
Revision	Description	Date	By

Scale: 1:1	Quantity: 3	Units: Inch
Material: Aluminum 6061-T6 - -		
Surface treatment: None		

Tolerances after any surface treatment
x/x ± 1/32
x.x ± 0.010
x.xx ± 0.005
x.xxx ± 0.002
∠90° ± 1/4°
roughness average: 63√

INO

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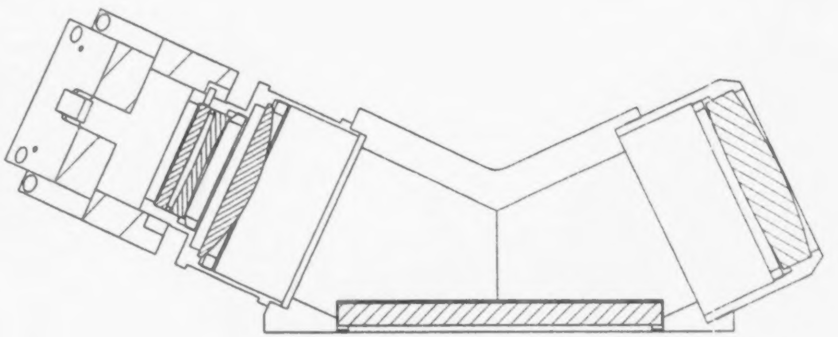
Sainte-Foy, Québec
Canada, G1P 4N8
Tel: (418) 657-7006
Fax: (418) 657-7009

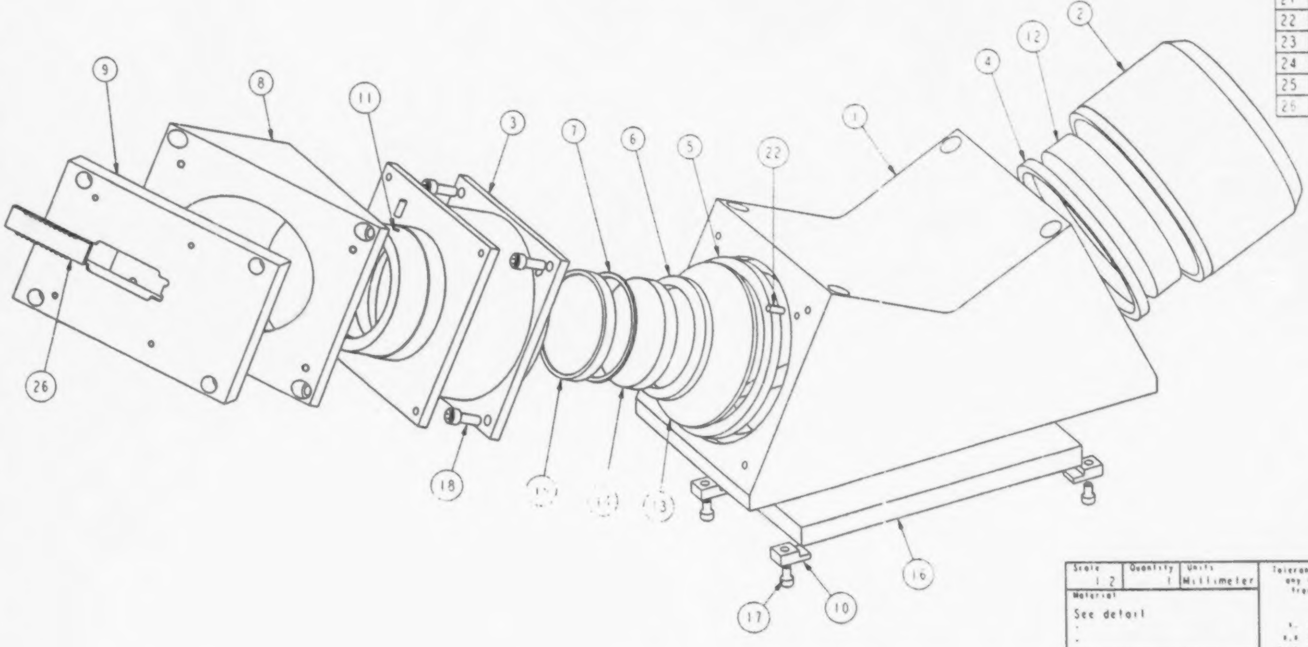
COUPLING ADAPTOR		
Designed: P. Gagnon	Verified: P.A.	
Drawn: S. Roy	Approved: P.A.	
Sheet 1 of 1	Software: Pro/E 2000i	Size A
10-Sep-99	7737-MPC069C	

ADAPTATEUR COUPLEUR

N°	DESCRIPTION	QTY	MATERIAL	DRAWING N°
1	MIRROR CELL, RECEPTION	1	ALUMINIUM	7737-MPC007C
2	HOUSING #1, RECEPTION	1	ALUMINIUM	7737-MPC008A
3	HOUSING #2, RECEPTION	1	ALUMINIUM	7737-MPC009B
4	HOLDING RING #1, RECEPTION	1	ALUMINIUM	7737-MPC010A
5	HOLDING RING #2, RECEPTION	1	ALUMINIUM	7737-MPC011A
6	HOLDING RING #3, RECEPTION	1	ALUMINIUM	7737-MPC012A
7	SPACER, RECEPTION	1	ALUMINIUM	7737-MPC013A
8	Z ADJUSTMENT #2, RECEPTION	1	ALUMINIUM	7737-MPC018B
9	DETECTOR SUPPORT #2	1	ALUMINIUM	7737-MPC019B
10	MIRROR SUPPORT BLOCK, RECEP	1	ALUMINIUM	7737-MPC016A
11	Z ADJUSTMENT RING, RECEP	1	ALUMINIUM	7737-MPC017A
12	BI-CONVEX DOUBLET LENS	1	CROWN & FLINT GLASS	M G LA0267
13	PLANO-CONVEX LENS	1	BK7	JML CPX10385
14	BI-CONCAVE LENS	1	BK7	JML CBV11080
15	INTERFERENCE FILTER	1	SODA LIME	M G 03FIV111
16	FLATE MIRROR	1	BK7 ALL COATING	C O C MREF110A
17	SHCS 6-32 x 1/4	4	--	--
18	SHCS 8-32 x 1/2	4	--	--
19	SHCS 8-32 x 1	4	--	--
20	SHCS 5-32 x 3/4	2	--	--
21	SHCS 4-40 x 5/8	2	--	--
22	DOWELL PIN Ø3 0 x 8 0	2	--	--
23	DOWELL PIN Ø2 5 x 12 0	2	--	--
24	SPRING (SPEC)	2	--	E01800220620
25	BALL Ø7 0	2	--	--
26	PHOTO DIODES ARRAY	1	--	--



SECTION A-A



IDT-034
ORIGINAL

Revision	Description	Date	By

Scale 1 2
Quantity 1
Units Millimeter
Material
See detail
-
-
Surface treatment
See detail

Tolerances after any surface treatment
x. ± 0 20
x.x ± 0 10
x.xx ± 0 05
∠90° ± 1/4°
roughness average ✓

INO
2740, Einstein St
Sainte-Foy, Québec
Canada, G1P 4S4
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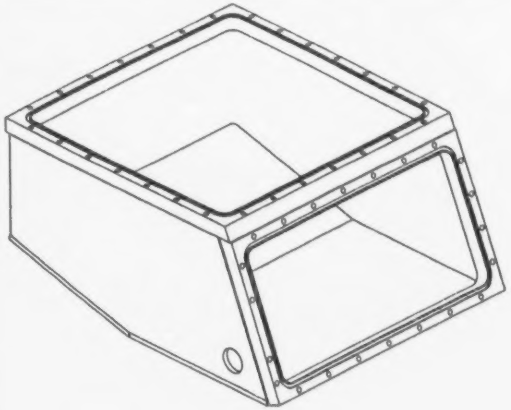
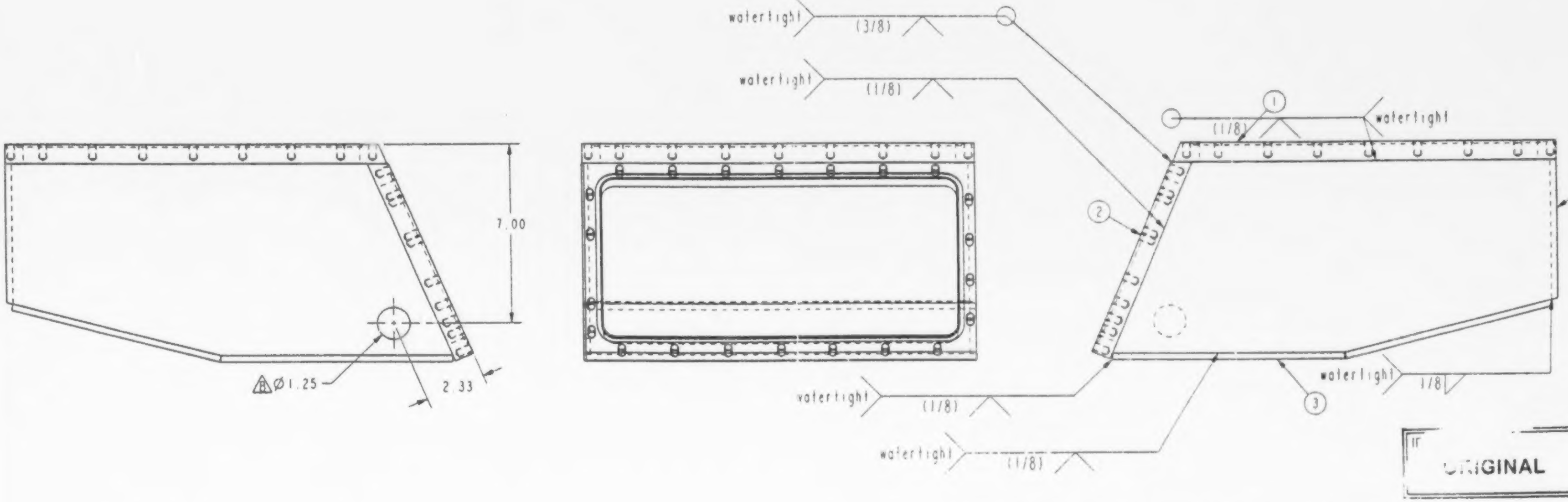
Fax: (418) 657-7009

RECEPTION
Designed P Gagnon
Verified
Drawn S Roy
Approved
Sheet 1 of 1
Software Pro/E 2000i
Size B
15-Apr-98
7737-MSA001A

N°	DESCRIPTION	QTY	MATERIAL	N° DRAWING
1	TOP FRAME, RIGHT HOUSING	1	-	B7737-MPC027A
2	FRONT PLATE, RIGHT HOUSING	1	-	B7737-MPC026A
3	BOTTOM FOLDED PLATE, RIGHT HOUSING	1	-	B7737-MPC024A
4	FRONT PLATE, RIGHT HOUSING	1	-	B7737-MPC025A




watertight
(3/8)
watertight
(1/8)
watertight
(1/8)
①
②
③
④
watertight
1/8
watertight
(1/8)
watertight
(1/8)
7.00
2.33
Ⓑ Ø1.25

ORIGINAL

Revision	Description	Date	By
B	SHEET #2 ADDED & HOLE ADDED	09/09/99	L S

Scale	Quantity	Units
1:4	1	Inch

Material
-
-
-

Surface treatment
Passivation after welding

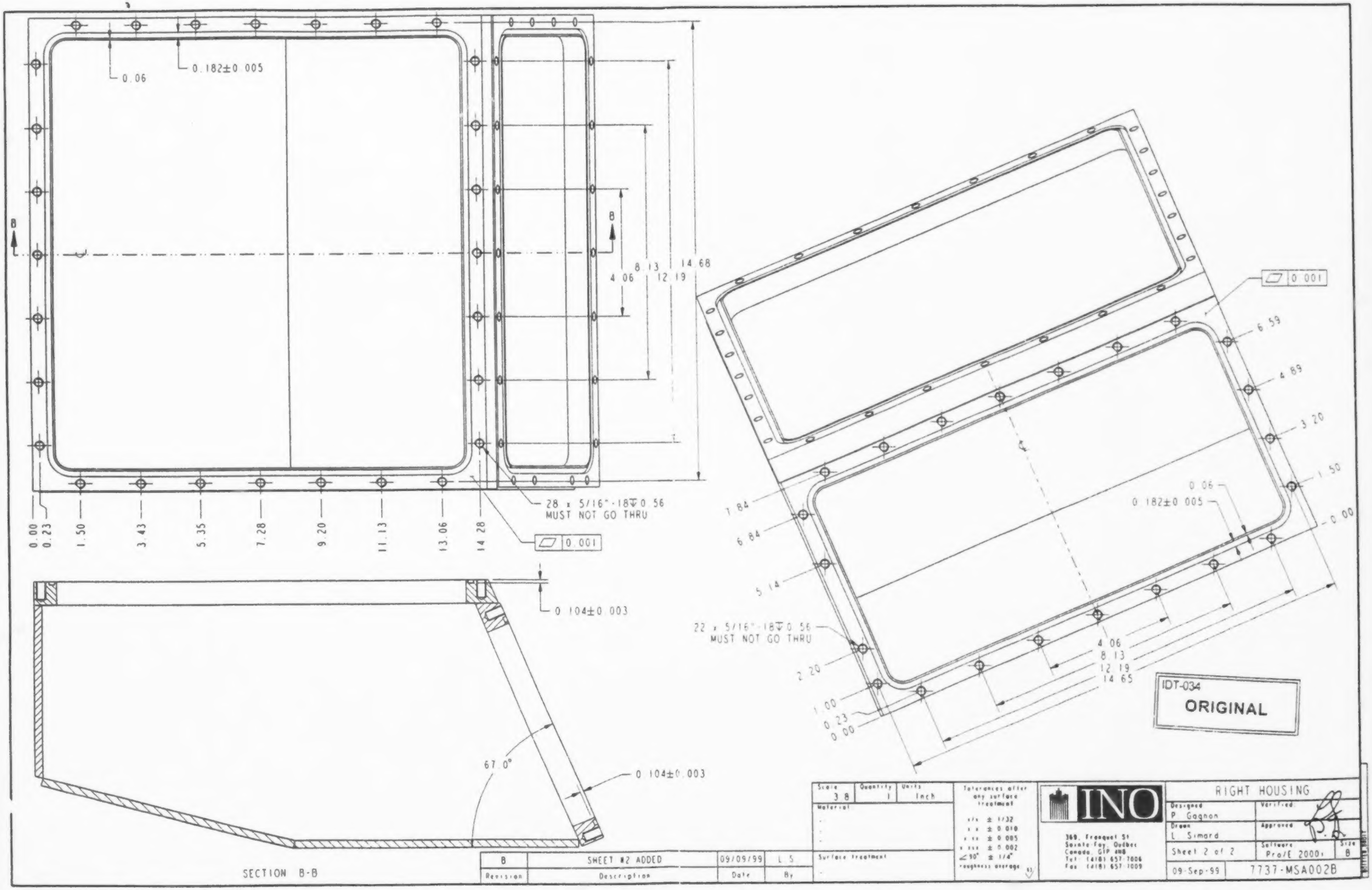
Tolerances after any surface treatment
x/x ± 1/32
x.x ± 0.010
x.xx ± 0.005
x.xxx ± 0.002
∠90° ± 1/4°
roughness average 63

INO
369, Franquet St.
Sainte-Foy, Québec
Canada, G1P 4N8
Tel: (418) 657-7006
Fax: (418) 657-7009

RIGHT HOUSING

Designed P. Gagnon	Verified
Drawn L. Simard	Approved
Sheet 1 of 2	Software Pro/E 2000i
28-Sep-99	7737-MSA002B

Size B



0.06
0.182±0.005
B
B
4.06
8.13
12.19
14.68
0.00
0.23
1.50
3.43
5.35
7.28
9.20
11.13
13.06
14.28
28 x 5/16"-18⊽0.56
MUST NOT GO THRU
⏥ 0.001
0.104±0.003
67.0°
0.104±0.003
SECTION B-B
⏥ 0.001
6.59
4.89
3.20
1.50
0.00
0.06
0.182±0.005
7.84
6.84
5.14
22 x 5/16"-18⊽0.56
MUST NOT GO THRU
2.20
1.00
0.23
0.00
4.06
8.13
12.19
14.65

IDT-034
ORIGINAL

Revision	Description	Date	By
B	SHEET #2 ADDED	09/09/99	L.S

Scale	Quantity	Units
3:8	1	Inch

Material
-
-
-

Surface treatment
-

Tolerances after any surface treatment
x/x ± 1/32
x.x ± 0.010
x.xx ± 0.005
x.xxx ± 0.002
∠90° ± 1/4°
roughness average 63/

INO
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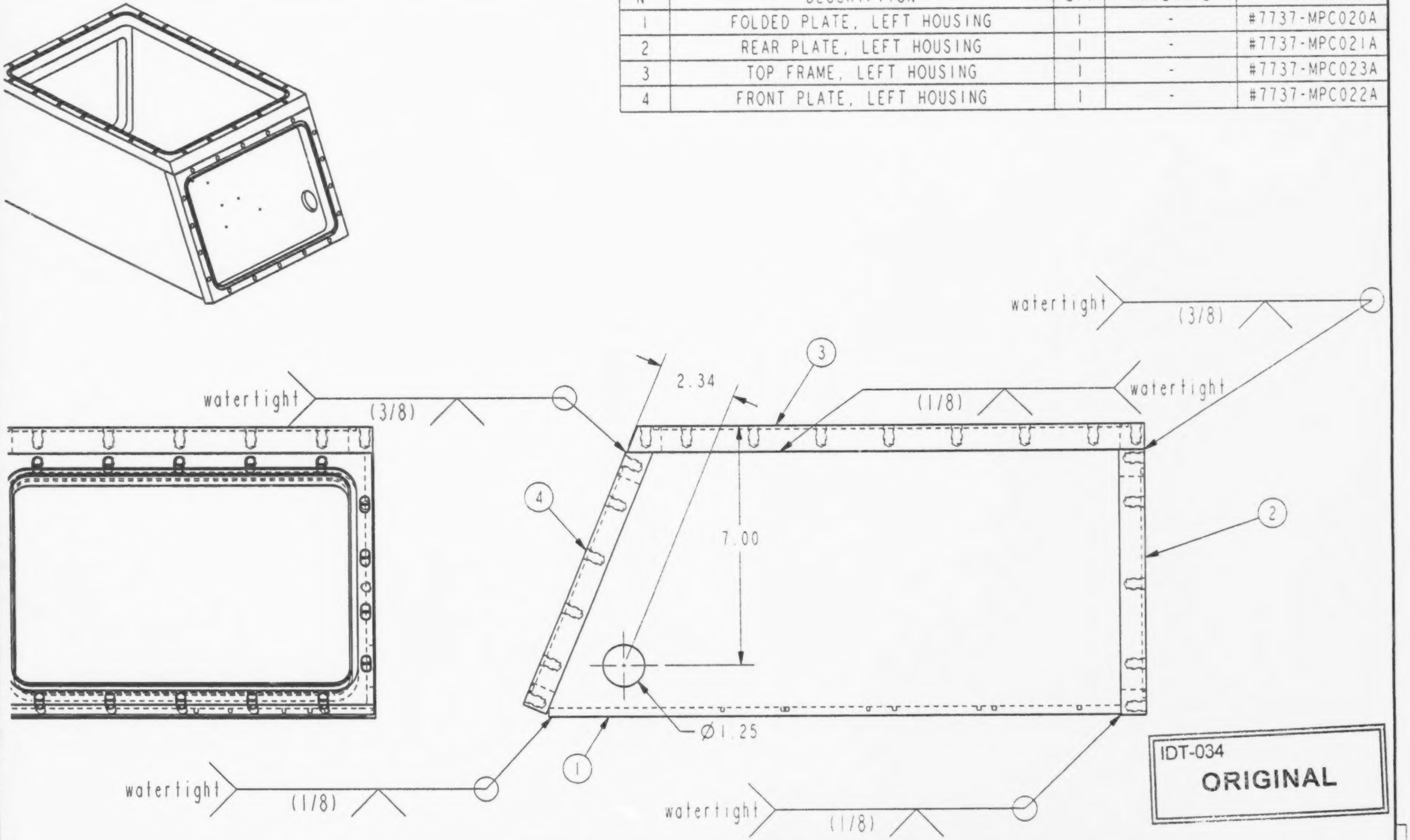
Sainte-Foy, Québec
Canada, G1P 4N8
Tel: (418) 657-7006
Fax: (418) 657-7009

RIGHT HOUSING		
Designed P. Gagnon	Verified	
Drawn L. Simard	Approved	
Sheet 2 of 2	Software Pro/E 2000i	Size B
09-Sep-99	7737-MSA002B	

N°	DESCRIPTION	QTY	MATERIAL	N° DRAWING
1	FOLDED PLATE, LEFT HOUSING	1	-	#7737-MPC020A
2	REAR PLATE, LEFT HOUSING	1	-	#7737-MPC021A
3	TOP FRAME, LEFT HOUSING	1	-	#7737-MPC023A
4	FRONT PLATE, LEFT HOUSING	1	-	#7737-MPC022A


watertight
(3/8)
watertight
(1/8)
watertight
(3/8)
2.34
7.00
Ø1.25
watertight
(1/8)
watertight
(1/8)
1
2
3
4

IDT-034
ORIGINAL

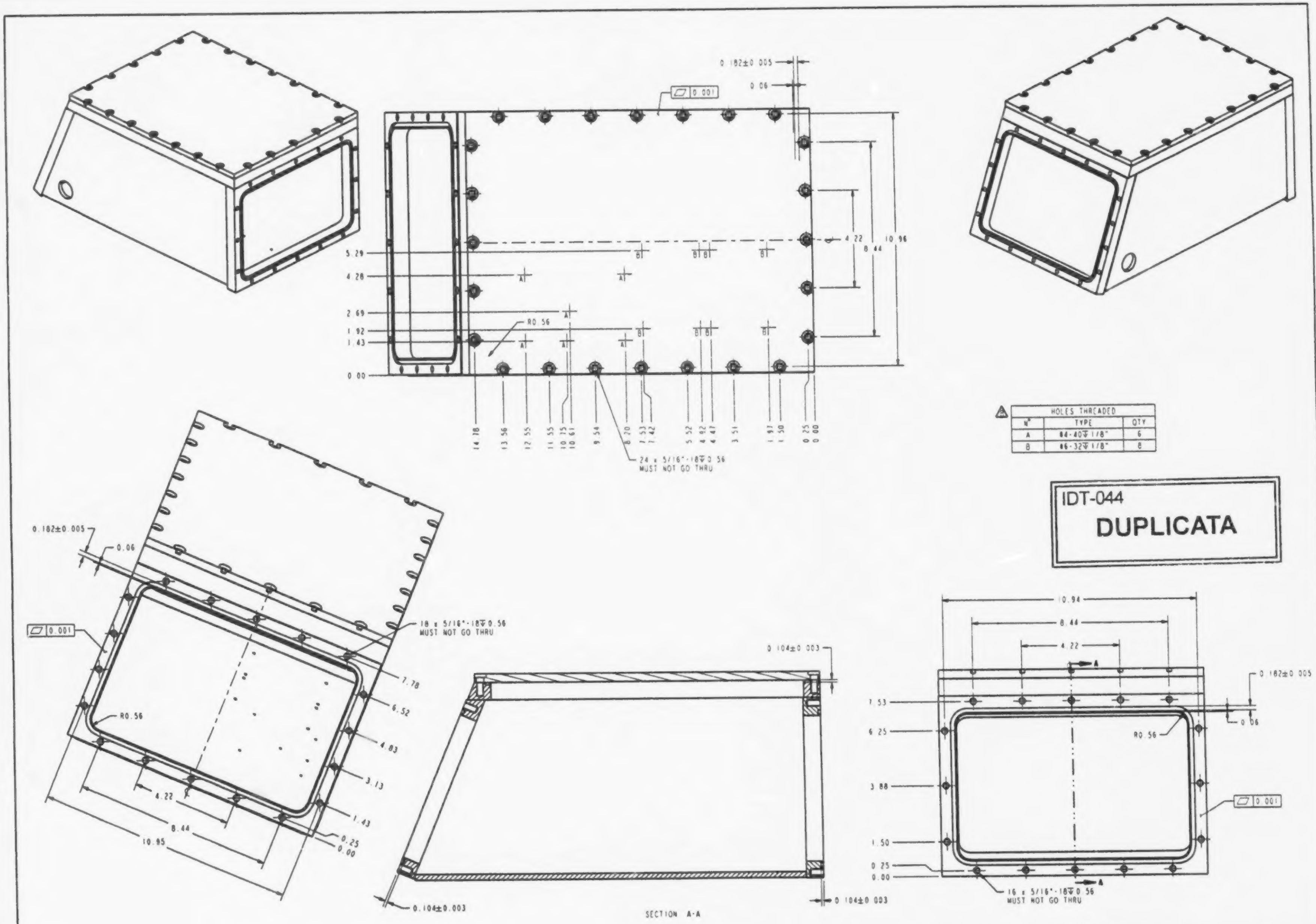
Scale: 1:4
Quantity: 1
Units: Inch
Material:
-
-
-
Surface treatment:
Passivation after welding

Tolerances after any surface treatment
x/x ± 1/32
x.x ± 0.010
x.xx ± 0.005
x.xxx ± 0.002
∠90° ± 1/4°
roughness average: 63

INO
369, Franquet St.
Sainte-Foy, Québec
Canada, G1P 4N8
Tel: (418) 657-7006
Fax: (418) 657-7009

LEFT HOUSING
Designed: P. Gagnon
Verified:
Drawn: L. Simard
Approved:
Sheet 1 of 2
Software: Pro/E Ver. 20
Size A
05-Aug-99
7737-MSA003C
BOITIER GAUCHE

B	SHEET #2 ADDED	09/09/99	L.S.
ision	Description	Date	By



0.182±0.005
0.06
0.001
5.29
4.28
2.69
1.92
1.43
0.00
R0.56
A1
B1
4.22
8.44
10.96
14.78
13.56
12.55
11.55
10.75
10.61
9.54
8.20
7.53
7.42
5.52
4.92
4.47
3.51
1.97
1.50
0.25
0.00
24 x 5/16"-18↧0.56
MUST NOT GO THRU
18 x 5/16"-18↧0.56
MUST NOT GO THRU
7.78
6.52
4.83
3.13
1.43
0.25
0.00
4.22
8.44
10.95
0.104±0.003
SECTION A-A
10.94
8.44
4.22
A
7.53
6.25
3.88
1.50
0.25
0.00
R0.56
0.182±0.005
0.06
0.001
16 x 5/16"-18↧0.56
MUST NOT GO THRU

⚠ HOLES THREADED		
N°	TYPE	QTY
A	#4-40↧1/8"	6
B	#6-32↧1/8"	8

IDT-044
DUPLICATA

C	HOLES ADDED	06/10/99	L.S
B	SHEET #2 ADDED	08/09/99	L.S
Revision	Description	Date	By

Scale 3:8	Quantity 1	Units: Inch
Material		
Surface treatment		

Tolerance after any surface treatment
x/x ± 1/32
x.x ± 0.010
x.xx ± 0.005
x.xxx ± 0.002
∠90° ± 1/2°
roughness average

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Sainte-Foy, Québec
Canada, G1P 4N8
Tel: (418) 657-7006
Fax: (418) 657-7009

LEFT HOUSING

Designed P. Gagnon	Verified	
Drawn L. Simard	Approved	
Sheet 2 of 2	Software Pro/E 2000i	Size C
09-Sep-99	7737-MSA003C	

INO

2740, rue Einstein, Sainte-Foy (Québec) Canada G1P 4S4
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